BEHAVIOR PATTERNS
OF
THE ALIMENTARY TRACT

T. WINGATE TODD

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BEHAVIOR PATTERNS
OF
THE ALIMENTARY TRACT

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PREFACE

When a distinguished teacher in any one of the great fundamental branches of medicine devotes adequate time and energy through practical experimental work on human subjects in adequate numbers, results of great value in clinical work are usually accomplished. The certainty of these values is enhanced when the studies cover reactions to simple stimuli necessary in daily routine living. When one's knowledge of the commoner things in life is well grounded, desired control of behavior can easily be made automatic. Doubtless, the simpler discomforts of life, and later their sequelae, involve greatest attention in individual health records.

Dr. T. Wingate Todd, in the Ninth Series of Beaumont Foundation Lectures, has made a useful record of gastro-intestinal observations, and has presented a point of view hitherto but little emphasized. In his own words this is the viewpoint of the behavior pattern. Attention has been given to the response of the digestive system to stimuli of local, reflex or central origin, and the studies cover the reaction of the stomach to very simple stimuli, such as, water, milk, acid, alkali and carminative, also to the responses of the tract to heat and cold, directly or indirectly applied, and to foreign bodies and to emotional interference. The subject material has consisted of groups of healthy young coöperative student subjects of both sexes. The experiments have included a considerable number of subjects and have been repeated on the same subjects under the same conditions until sufficient data were gathered to give confidence in the uniformity of response. Actually over four hundred students assisted as subjects in this experimental work.

The permanent records have been made from roentgenoscopic sessions, actual roentgenograms with serial studies and motion picture reductions.

The central theme of this work is the fundamental significance in health and in disease of the behavior pattern in the alimentary tracts of students. This work may serve as an example to be followed, amplified and extended by the physician in his office.

The Beaumont Foundation Committee of the Wayne County Medical Society commends to the reader a careful perusal of this valuable and practical work.

(Signed) J. E. Davis, A.M., M.D.
For the Committee
W. M. Donald, *Chairman.*
J. E. Davis.
W. E. Blodgett.
H. W. Plaggemeyer.
J. H. Dempster.
E. C. Baumgarten.
W. S. Reveno, *Secretary.*

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PART I

Principles of Gastric Motility

INTRODUCTION

In presenting the following brief report of investigations upon the behavior patterns of the alimentary tract I should like to pay a simple tribute to the memory of the man whose assiduous observations, patiently carried on even under extraordinarily adverse conditions, laid the foundations for an adequate understanding of gastro-intestinal function, William Beaumont. It is the knowledge of Beaumont's doggedness which has inspired my many associates and myself to try again and yet again through many weary days when evidence has appeared equivocal and difficulties insurmountable. The record which is now so simple in its principles and so complete in its details has been obtained at great cost in human persistence and is itself a monument to the whole-hearted and loyal coöperation and to the unstinted devotion of the hundreds of students of both sexes who have given their time and their own bodies to the elucidation of our problems.

When in 1908–10 I was engaged in a study of the alimentary tract by such roentgenoscopic facilities as we then had, I found myself so constantly confronted with difficulties of interpretation that I planned, at that date, the investigations now reported. It was necessary to wait until X-ray technique had been improved and until I should be in a position to gather the necessary funds and personnel to carry on the work. In 1924 assistance and funds were provided and students in sufficient number joined Miss W. M. Kuenzel and myself in the investigation. Since then we have carried out our program stage

by stage. During the lapse of twenty years the need for a long-continued, large-scale investigation of normal alimentary tracts has grown more imperative. There have been however very careful and thorough studies from both physiological and anatomical aspects, the former balanced and amplified by animal experimentation. During these years also our knowledge of the activities of the tract has steadily increased. It is not my desire to set these aside. Our purpose has been to attack the problem of the alimentary canal from the standpoint of the clinician and radiographer, checking our interpretations by the observations of Cannon (2), Carlson (3), Ivy (5), Alvarez (1) and those who, with them, have contributed so handsomely to our common stock of knowledge. Nor would we ignore those, in other countries, who have made our labor easier by their own. Having however once sought to do justice to other investigators in book form (13), it has been evident that this can be attained only by drastically curtailing our own observations. In the small compass of this book therefore I propose to set forth the record of our own work, with a discussion tempered by knowledge of the investigations of others to which space permits but scant allusion.

TECHNICAL METHODS

The very simplicity of administration of a barium meal and examination on the roentgenoscopic screen predispose the observations to error and elaborate precautions must be adopted in consequence.

It must be constantly borne in mind that the stomach and bowel are stimulated to activity by the presence of contents, and this activity has both mechanical and chemical aspects. There could be no graver error than the assumption that the tract will respond passively or even in constant manner to the administration of contents

either by mouth or rectum. There will be a response, it is true, to the presence of contents but the precise details of the behavior pattern, following the meal, will depend upon the interplay of other factors directly or indirectly called into action by our procedure. It becomes our endeavor then so to analyze the features of the behavior observed that we may recognize and segregate out the characteristics of each factor which has a bearing upon the observed pattern.

It is impossible to investigate the empty stomach or bowel for unless contents be present, not necessarily barium of course, the organ outlines cannot be observed by roentgenoscopy. Nor must we assume that the contents in either stomach or bowel are limited to the amount which we administer. Secretion very rapidly modifies the picture in the stomach and the presence of previous contents may influence the bowel picture. It will be necessary, in succeeding chapters, to take up this aspect in further detail.

The precise position of the organs in the abdomen has been often investigated as an anatomical study and Moody's quite comprehensive work may be taken as an authoritative presentation of the facts so far as this method of study will reveal them (11). Their position depends upon temporary adjustments with other viscera, upon the amount of contents and the state of tone of the muscular walls of the organ under observation. The registration of site depends upon landmarks, namely, vertebral shadows, iliac crests or umbilicus, which are not themselves quite constant in position. Size of organ shadow depends upon distance of screen from the organ and since the different parts of stomach and bowel are not equally distant from the screen any consideration of dimensions of shadow must take into account the position of the organ within the abdomen.

Record of the behavior pattern may be made, as other observers have shown, by the automatic registration of balloon and tambour. The presence of the balloon itself modifies the behavior pattern and may mask the response called forth by the stimuli the influence of which one seeks to investigate. Consequently the balloon and tambour method must be replaced by time-clock and dictaphone whereby essential features of behavior may be entered on the record with as close an approximation to time as is humanly possible. With relatively slowly acting smooth muscle mechanisms this, in practice, is a fairly satisfactory method despite obvious disadvantages. Indeed a skilled assistant, stationed with a time-clock registering seconds on a large dial, can check off with sufficient accuracy the time relationship of the several features in a behavior pattern as these are called out by the observer, provided the method of procedure is carefully rehearsed in advance.

The graphic presentation of a behavior record involves fresh but not insurmountable difficulties. From time to time discoveries have been announced of methods by which the roentgenoscopic picture can be photographed or a photographic film substituted for the roentgenoscopic screen. We owe a great deal to Lewis Gregory Cole for his pioneer efforts in this aspect of the work. It stands to reason however that no continuous or practically continuous record can be made for more than a very brief period without jeopardizing the subject of investigation. The very few minutes during which this record can be made are altogether too short a time to enable one to register the sequence and course of alimentary responses. For this we have substituted a serial roentgenographical study in which the time-interval between exposures is determined by the nature and speed of the responses which it is desired to study. With an adequately trained team of assistants

and four cassettes photographic records can be made at intervals of ten seconds. This is usually the speed at which we make our serial photographs which are then reproduced on moving picture film of standard size to facilitate comparison with observations previously made on the roentgenoscopic screen. This photographic record merely amplifies and illustrates the roentgenoscopic observations:

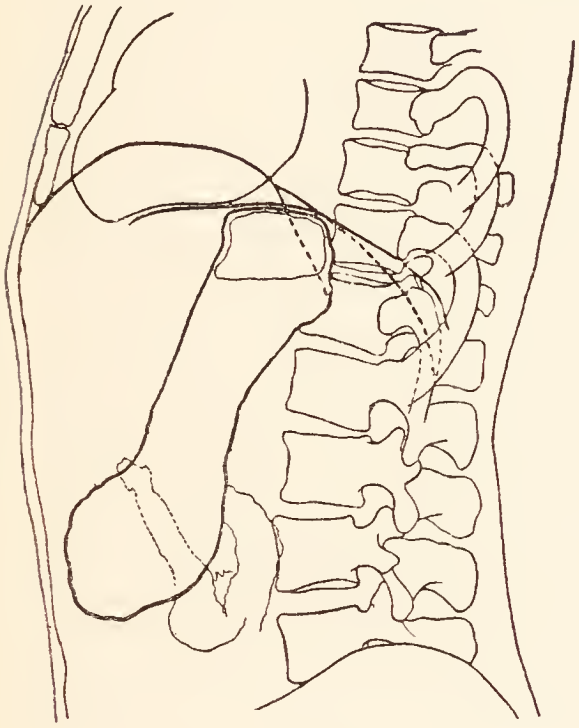


Fig. 1

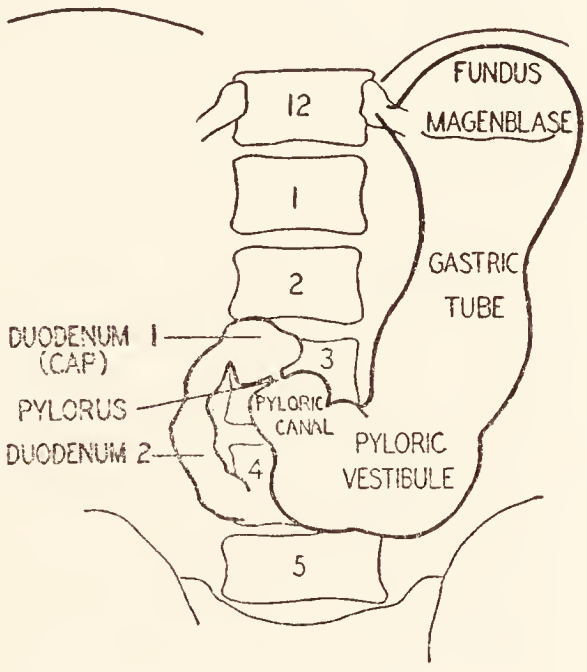


Fig. 2

Fig. 1. Left lateral view of torso to show the general relation of stomach to ventral abdominal wall. It is clear that the greater distance of the fundus will result in exaggeration in size of its shadow.

Fig. 2. General subdivision of the stomach.

It is no substitute for them. It can be made only upon a subject who has been trained to the conditions of the experiment and is himself entirely coöperative.

In all that follows I desire to associate with myself Miss W. M. Kuenzel who, as instructor in charge of roentgenography, is jointly responsible for all experiments. I would not however saddle her with equal responsibility for the opinions herein expressed.

GENERAL FEATURES OF THE STOMACH

The roentgenoscopic picture gives a more accurate idea of the dimensions of the pyloric portion of the stomach than of the cardiac part since the latter is further removed from the screen. The relations of the organ in the abdomen are presented in Figure 1, the subject standing erect. Figure 2 shows the subdivisions of gastric and duodenal shadows as we shall refer to them in the text.

In its position the cardia only is approximately constant, being held by its relation to the diaphragm. In our experience of the young male White the modal position for cardia shadow is at the level of the twelfth thoracic vertebra both in vertical and horizontal postures. The pylorus is more variable, the median example of a series lying at the upper level of the third lumbar vertebra when the subject is erect and at the lower level of the first lumbar when he is horizontal. The level of the lowest point on the greater curvature is so variable that one hesitates to make any statement. However in one of our series the greater curvature, in the erect posture, reached, in the median, the mid-level of the fifth lumbar vertebra but rose considerably on changing to the horizontal so that the median now lay at the level of the disc below the second lumbar. With change from the vertical to the horizontal posture a rise equal to two or even three vertebrae is usual. It is invidious to dwell upon average or even modal levels of these gastric landmarks. The position of the stomach is not susceptible of simple statistical analysis. Not only is the individual significant, his general bodily form, race, sex and age, but also the amount and character of the meal and his emotional and general health status for the time being. Hence I should class gastric condition as even less reliably represented by levels than a child's development is indicated by his height-weight index or an adult by the closure of his sutures.

Elsewhere attention has been drawn to the change in gastric position and in shadow form by an alteration in bodily weight (15). There is naturally no uniformity in this change but in our experience the healthily corpulent have small highly placed gastric shadows and equally healthy people, more meagerly endowed with abdominal fat, have long gastric shadows extending low in the abdomen. My own stomach shadow was entirely changed in shape and area by the loss of twenty pounds in weight, occurring during twelve months without loss of health. Statements concerning the relationship of gastric form to constitutional type, going further than this, seem to me ill-substantiated.

Allied in practice to the definition of gastric levels is the relative position of the target in the Coolidge tube used for making photographic records. Miss Kuenzel and I have shown that there is no significant modification in shadow levels resulting from moderate fluctuations in target level. We do try to adjust it as nearly as possible to the level of the disc below the second lumbar vertebra but this is more for uniformity of technique than for any anticipated effect upon our results (15).

A really important consideration in gastric studies is the season of the year. Both in their tone and in their peristaltic activity we find our student stomachs much less active and reliable in February than in October (15). Doubtless this is related more to conditions of life in the late winter than to actual climatic phenomena. Yet it is significant that Doctor G. M. Higgins (4) reports similar findings in frogs and turtles. We are in the habit of pointing out the logical date of Lent in the calender and the exacerbation in symptoms of pyloric and duodenal ulcer and irritation during the bad weather of February and March as probably related to these findings. We never now, if it can be avoided, pursue any gastric experiments during the later winter.

It has already been mentioned that size of meal profoundly influences the behavior pattern. The result is evident in peristaltic activity as well as in shadow dimensions. A stomach containing a meal of sixteen or twenty ounces may not show the maximum characteristic peristaltic activity for twenty or thirty minutes after the meal is administered. A five-ounce meal results in maximum peristaltic activity within three to five minutes and after a half-ounce meal the peristalsis develops its characteristic pattern in from two to three minutes. Likewise the temperature of the meal must be controlled for both heat and cold bring about modifications of shadow dimensions and peristaltic activity so definite that they will receive attention later in this report.

We do not starve our subjects preparatory to experimentation for we find that one and a half or two hours after a light breakfast or lunch the gastric contents have already passed through the pylorus and the stomach is empty. This non-interference with daily dietary habits we regard as of considerable importance in fostering natural gastric behavior during the period of study.

THE IMPORTANCE OF EMOTIONAL STIMULI

It goes without saying that self-originated states such as those employed by the introspective school of psychologists will find no representation in gastric behavior. It is indeed doubtful if one can, by will power alone, institute thorough-going emotional states such as anger, fear, pleasure or mental peace.

It is also apparent that stomachs of which the behavior pattern is already influenced by the presence of a foreign body such as a balloon cannot register adequately the effect of emotional stimuli though even under such conditions Carlson has shown the influence of sleep upon gastric behavior (3).

The effect of emotional stimuli, under which term we would include all impulses of higher central nervous origin, is very strikingly seen in stomachs investigated by the technique which we employ. These influences group themseves into three categories:

A. The purely temporary effect of mental shock.
B. The more prolonged results of mental distress.
C. The long sustained modification of behavior pattern by mental strain.

Our attention was first drawn to the very definite influence of the emotional state upon gastric behavior by the striking distinctions between Freshmen and Sophomore stomachs both in shadow dimensions and motility. Since both sets of observations were made in the month of October the stomachs were examined under thoroughly comparable and quite advantageous conditions. The lack of tone, or rather the difference in the length-phase of the smooth muscle, and the interference with peristaltic rhythm were glaringly obvious in most Freshmen. As the examinations were repeated on each student first in his Freshman and then in his Sophomore year it is evident that the difference in behavior is to be explained by some condition of the experiment and is not an individual difference. Associated most frequently, but not invariably, with lack of tone and inhibited peristalsis are certain external signs such as pallor, flushing, dryness of the mouth, staccato speech, a cold and clammy skin, perspiring palms and a slightly ataxic gait. These manifestations of disquietude are seen only in Freshmen. At first we associated the peculiar behavior of the stomach with the drinking of iced water which we observed in these students. However since we shut off the drinking fountain and made an elaborate study of the gastric responses to cold and to water we were compelled to abandon this theory. We

came to regard the water-drinking itself as a manifestation of nervousness. In two articles already published (14, 17) this emotional control of gastric behavior has been fully presented. I will therefore content myself with a very brief statement.

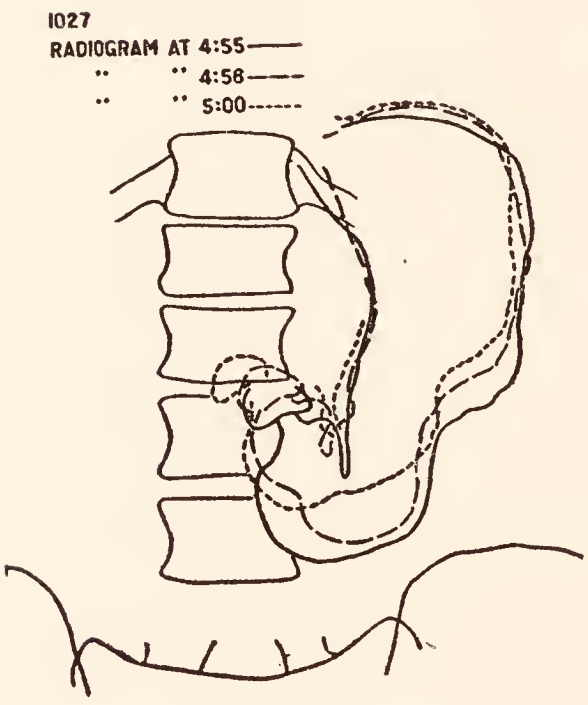


FIG. 3

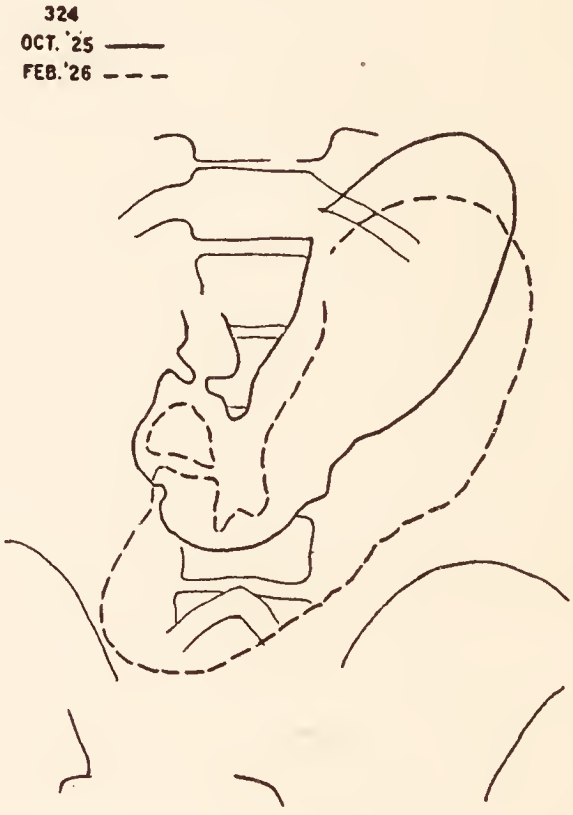


FIG. 4

FIG. 3. Initial effect of and recovery from mental shock. Note: progressive restoration of orthotony with more rapid return of peristaltic wave.

FIG. 4. Hypotony of acute mental distress. Note the inversion of greater curvature level.

Momentary effects of mental shock are very frequently seen when a student steps behind the roentgenoscopic screen, especially if he has not been the subject of many experiments. We may have to wait for one minute before the inhibited peristalsis again attains its characteristic vigor or even before it appears. There is a low insulated platform on which the student stands. If he stumbles in stepping on to this platform we frequently see the sudden

drop and more gradual recovery of the greater curvature which accompany the shock to his balance.

A slight mischance like the slipping of the operator's thumb on the timing switch during a roentgenographic exposure or even the taking up of position at the photographic stand will bring about this sudden hypotony and inhibition of peristalsis. Figure 3 shows the initial effect of and the recovery from a mental shock caused by awk-

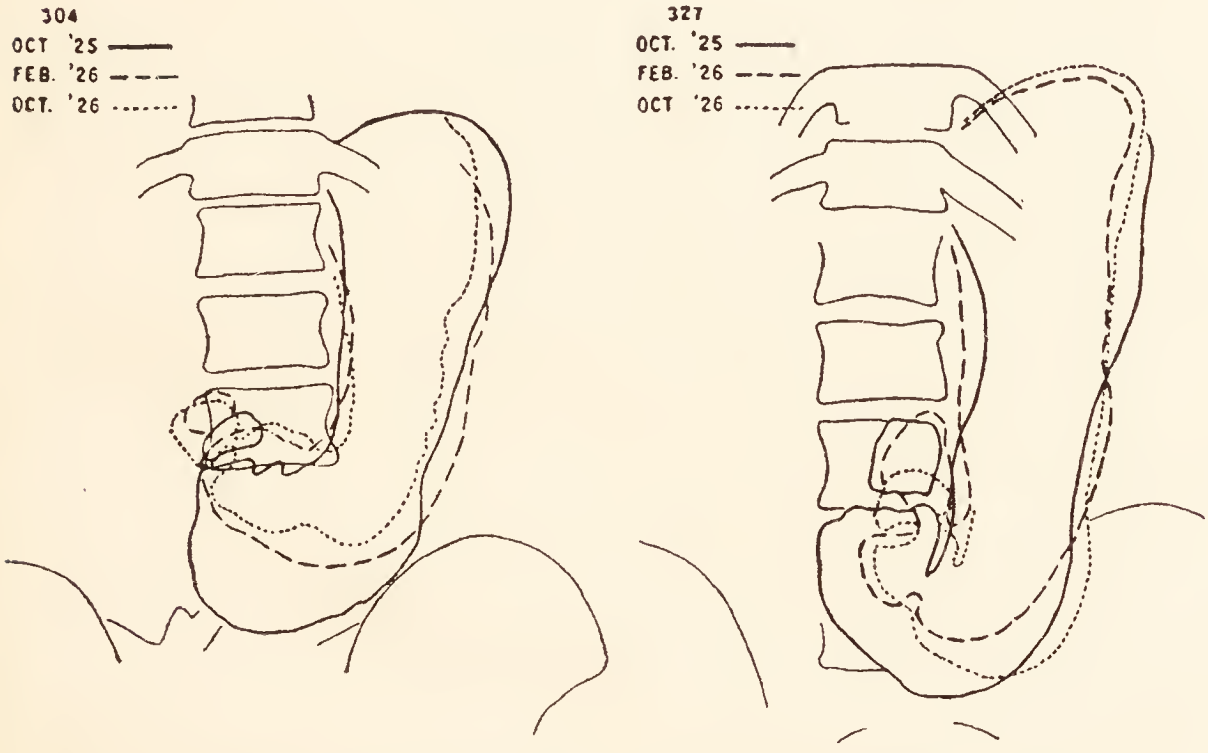


FIG. 5. Effect of depressing mental conditions. Note the inversion of greater curvature level in No. 327 who was in apprehension of compulsory retirement from a medical career.

wardness of the operator at the switch. Peristalsis invariably returns before the stomach regains its orthotony. These untoward effects can often be avoided if the student is warned ahead of time what he may expect. The acute mental distress induced by the shame of impending expulsion is responsible for the hypotony seen in Figure 4. The peristalsis of this stomach was approximately normal on the day the second roentgenogram was made for our record is explicit on this point. In another quite similar case,

when we were able to examine the student on the very day of his accusation, we found peristalsis absolutely inhibited and we were unable to evoke it even by the relatively strong stimulus of buttermilk. Since we already knew the behavior pattern of this stomach from many experimental studies and knew also its susceptibility to the stimulus of buttermilk there is no question in my mind concerning the accuracy of the conclusions.

Depressing mental conditions such as repeated failure at examinations and uncertainty regarding academic standing are equally powerful in their effect on gastric behavior. Figure 5 contrasts the record in October 1926 of two students put under fear of compulsory retirement from the Medical School because of deficient scholarship. Two weeks after these records were made No. 304 was restored by the Committee on Students to full Sophomore status, No. 327 was formally required to cease further medical training with us. One might almost suggest that the decision of the Committee was foreshadowed in the roentgenographic pictures of the students themselves. Depressing mental conditions reduce the amplitude of but do not inhibit the peristaltic waves.

Allied to the effect of depressing mental strain is the effect of fatigue. We have learned never to make a gastric study of a subject who is at the end of a long day of heavy mental exertion or in the midst of a press of academic work which is robbing him of sleep and affecting his appetite. Similarly we avoid making examinations of students who have acted as donors for transfusion within a week or who are in the early stage of a feverish cold or influenza. We have found also that our girl subjects show hypotony and reduction in amplitude of peristalsis during the onset of menstruation and the day or two preceding this. Once menstruation has fully started, gastric orthotony and peristalsis normal for that subject are fully restored.

From experiences like those just recounted we hesitate to accept as satisfactory the first roentgenoscopic record of a patient unused to this form of examination. In our own examination of patients we are careful to adopt a safeguarding routine which will be described later.

One may ask how long the necessary period of training lasts. In our experience defective results are obtained in the first study only, provided the examination be carried out in perfect order and quiet, devoid of embarrassment, interruption and distraction. In order to ascertain this most important fact we have used as subjects of repeated examination medical and non-medical students of both sexes under varying conditions of peace of mind. There is no doubt that the human subject quickly resigns himself to the care of his physician and we believe that the preliminary "training" can be accomplished on the morning itself of the real diagnostic examination.

THE GROUP RESPONSE

Before leaving the problem of emotional states it is necessary to make a brief reference to what Miss Kuenzel and I have termed the group response (15). By this we mean the evidence of emotional interference or influence on gastric behavior exhibited by the students as a class rather than as individuals. As the years passed and our collaborating students came to understand better that they were not merely serving as subjects for experimentation but actually themselves carrying out investigations on each other under the direction of the Staff, our results improved. The unexpected and inexplicable varieties of response gradually became replaced by a stable, almost uniform, behavior pattern which, under the circumstances of Sophomore examination, could be predicted. It became actually possible to discuss with the class the several phases of gastric activity and expound in

detail how we proposed to modify the pattern by appropriate methods and then to demonstrate upon these very students the gastric behavior which we had forecast. After five years of this coöperative work we now discuss with the class the experiments to be undertaken and the results which will be demonstrated without fear of failing in our self-appointed task. This uniformity of gastric behavior and this control over its pattern are the inevitable consequence of the development, among the students themselves, of a wholly coöperative spirit and a sympathetic understanding of the efforts of their instructors to give them first-hand observation of normal human gastric function.

It is not so easy to present evidence of this very significant and wholly unexpected observation. We have however attempted to illustrate it in a survey of planimetric records of shadow areas. Elsewhere we have crudely expressed the Freshman stomach as being "too large for its contents" (16). By this we mean simply that given like conditions and a uniform size of meal the gastric shadow dimensions of the Freshmen are greater than those of the Sophomores. The initial hypotony is a measure of the collective mental disquiet on the part of Freshmen.

Again there are delayed release of gastric contents through the pylorus and diminution of gastric activity in mental disquiet. Hence, without entering into a discussion of the shadow area as a measure of gastric volume or of the functional activity which is responsible for shadow dimensions, we may compare the shadow area at the end of an hour with the shadow area immediately on swallowing the meal. This has been done for two successive classes in Table I.

It must, of course, be understood that comparisons can be made only of the records of a single group. There cannot be comparison of shadow areas for successive groups.

The first group (Class of 1928) was examined first in February, a bad month as we have already indicated. That it actually is a bad month is demonstrated by the average shadow areas for October 1925 and February 1926 of the second group (Class of 1929). There is no reduc-

TABLE I

Comparison of Freshman and Sophomore areas

Records from radiograms taken 10 minutes after 16-ounce meal

	YEAR	AVERAGE AREA	DIFFERENCE
		sq.mm.	
Class of 1928:			
Freshmen (A_1)	February, 1925	21,545	
Sophomores (A_2)	October, 1925	18,163	3,382 ($A_1 - A_2$)
Class of 1929:			
Freshmen (B_1)	October, 1925	22,829	
Freshmen (B_2)	February, 1926	22,900	2,379 ($B_1 - B_2$)
Sophomores (B_3)	October, 1926	20,450	2,450 ($B_2 - B_3$)

Record of reduction in area from 10 minutes to 1 hour after meal

	YEAR	AVERAGE 10-MINUTE AREA	AVERAGE 1-HOUR AREA	DIFFERENCE
		sq. mm.	*sq. mm.*	*sq. mm.*
Class of 1928:				
Freshmen	February, 1925	21,545	17,343	4,202
Sophomores	October, 1925	18,163	13,720	4,442
Class of 1929:				
Freshmen	October, 1925	22,829	18,913	3,916
Freshmen	February, 1926	22,900	18,077	4,823
Sophomores	October, 1926	20,450	14,690	5,760

tion in average area in this class between October and the following February. We may then take the February 1925 record of the Class of 1928 as practically equivalent to what their average area would have been in October 1924 had it been observed.

Coming to the last column of the Table we see that the reduction in average area between Freshman and Sophomore stages is less in the class of 1929, not because their final shadows were of smaller dimensions than those of the previous group but because their initial shadows were large.

The second part of the Table shows the progressive diminution in shadow area during the hour after feeding. The improvement in the class of 1929 over that of 1928 is very marked indeed.

This demonstration is, we believe, the first attempt to register physically the change in mental attitude of a group of human beings. It is, in other words, an essay in collective reaction patterns.

ENTRY OF BARIUM INTO THE STOMACH

The entry of barium into the stomach presented, in our earlier work, so many varied patterns that we were completely at a loss to understand their significance. We therefore registered our observations and classified them in an earlier publication (16) for future analysis. The clue came when we found that, in certain Sophomores with a thin abdomen readily penetrated by X-rays, we were able to see the outline of fundus and gastric tube before the barium was swallowed. While the student stood behind the screen, holding in his hand the glass of barium vehicle, the dim grey outline of the gastric tube distended laterally as though the stomach were filling with fluid. The nature of this fluid and whether it is secreted in the stomach or is merely swallowed "psychic" saliva are problems into which we need not enter at the moment. We have not seen the phenomenon in the typical Freshman stomach but we believe it does occur because the progress of the barium sifting through fluid is obvious in Freshmen as well as Sophomores. We there-

fore believe that when the barium appears to fill up from below, to trickle down the greater curvature or to sift through obvious fluid, the opaque meal is encountering a fluid in the stomach. In view of these inferences it is not clear at once why we do not assign the fluid to the remains of breakfast or lunch. Our reasons are two. First we have seen the fluid collecting rapidly immediately before administration of the barium. Secondly a stomach shows this phenomenon only in the untrained Freshman stage and at the first October meal in a Sophomore who has been away from the laboratory and X-ray technique for some months or is otherwise plainly nervous or upset.

In the absence of these modifying circumstances entry of barium occurs as a trickle down the lesser curvature spreading laterally as the gastric tube distends by a visible rapidly accumulating fluid.

NAUSEA AND VOMITING

There is however another type of filling which is not infrequently encountered especially on the administration of our experimental meals, the taste of which is unequally palatable to different subjects. We refer to the accumulation of barium in the cardiac portion of the stomach as though held up by spasm of the gastric tube. We have learned by experience that this is a phenomenon of physical nausea. When it occurs we watch very carefully the behavior of the diaphragm. Most often the regular respiratory rhythm is maintained. Sometimes however flickering of the cupola is apparent. Should this flickering be replaced by a spasmodic descent of the diaphragm (in which we find both cupolae coöperating) projectile vomiting results. In our experience vomiting empties the cardiac part of the stomach which is first separated from the pyloric vestibule by spasm of the gastric tube and then cleared of contents by sudden diaphragmatic compression.

We have never had the opportunity to note the mechanism of possetting nor yet of the overflow-vomiting of intestinal obstruction.

THE BARIUM PICTURE OF GASTRIC BEHAVIOR

I. The mucus plug

Quite often in our earlier work, and occasionally still, we have seen the barium sinking down around a clear globular or mulberry-like mass of some substance with which it would not mix. This gives the barium shadow a flocculent appearance. In other stomachs the barium would reach the pyloric vestibule or commencement of pyloric canal and progress no further. It was clear, from the truncated shadow in these instances of inhibited progress, that spasm of the pylorus or adjacent part of the stomach could not be invoked as a cause. We usually find that the block is relieved after approximately two minutes and the barium then penetrates the pyloric canal and passes through the pylorus.

If the barium merely sinks around a clear mass we see that mass apparently detach itself from the lower pyloric vestibule and slowly "float" upward through the barium until it lies in the gastric tube above the dark shadow.

By turning the subject sideways it is easily seen that this light mass is in the stomach itself. We note its occurrence especially in students who have been unable to resist the attraction of the iced water fountain immediately previous to the roentgenoscopic examination. We find it in trained stomachs which show no hypotony or peristaltic anomaly as definitely as in untrained stomachs although, in the former, it occurs more often as a pyloric plug than as a mulberry mass. It may even appear at the beginning of a serial roentgenographic study. Miss Kuenzel has studied this puzzling phenomenon with great care but it was finally

solved by Mr. Sommerfield, who, attempting to withdraw gastric contents from a student, found the tube blocked by a thick mucus (9). There seems no doubt that the mucus is actually formed in the stomach (18), and that it is one of the physical features which may accompany a state of nervous tension. It is however related to what we shall later term the anxiety complex, not the distress complex.

II. Barium mixture

The physical relation of barium to the vehicle in which it is administered can be of very great service to the observer. In water or such watery solutions as sodium bicarbonate or peppermint the barium quickly separates from the supernatant fluid. It lies, an inert precipitate, clinging to the mucosa of the greater curvature and is only accidentally carried over into the duodenum by the fluid which circulates through the stomach. Suspended in milk the barium separates out only slightly less easily: in a thick fluid like buttermilk it remains largely suspended throughout the vehicle and, in consequence, renders more equally visible the entire extent to which the vehicle penetrates. For observing filling defects, polypoid masses especially if on the lesser curvature, and the duodenal cap, buttermilk is most useful. If however an outline of greater curvature alone is desired for experimental purposes later specified a water vehicle should be chosen.

One must not be under any misapprehension about the length of time barium can remain in the stomach. If the opaque salt is thoroughly supended it is removed from the stomach with the vehicle: if it separates out it may remain clinging to a healthy mucosa for hours. One of the most striking phenomena we see is the immediate sweeping through the pylorus of residual barium from a previous milk meal when a new meal of buttermilk is administered.

III. The barium precipitate as a motility indicator

Many people receive with caution statements of gastric activity demonstrated by barium, feeling that perhaps the barium itself, by its physical or even some obscure chemical properties, may influence the behavior picture. That there is no foundation for this apprehension can be demonstrated by the use of an "outliner."

An outliner is a half-ounce of water into which have been stirred five grams of barium sulphate. This is just enough to outline effectively the greater curvature. The barium very rapidly separates out from the water and clings to the mucosa where it will remain for from ten to twenty minutes during which the behavior of the stomach can be watched with ease.

As the barium reaches the greater curvature it is seen that there are waves of peristalsis passing over the stomach throughout the entire extent delineated by the barium. That the waves are preëxisting and merely outlined by barium, not stimulated thereby, is obvious from the instantaneous appearance of the peristalsis. There is no latent period. Of course the outliner must not be administered immediately to a stomach whose reactions are unknown. It is necessary to wait a full minute for the reëstablishment of peristalsis inhibited, as we have described, when the subject moves to the screen. Touching the patient's abdomen without warning or otherwise disturbing him may delay the return of peristalsis or cause fresh inhibition.

The speed and number of peristaltic waves continue unchanged but between one and a half and two minutes after the outliner is swallowed the depth and forcefulness of the waves increase rapidly to a maximum which is maintained for a period of about five minutes. Then depth and forcefulness become again reduced and the peristalsis returns to the type originally seen.

The weight of the barium outliner is negligible. The latent period always occurs before change in character of peristalsis is seen. The period during which this modification persists depends on the nature and amount of the vehicle. The behavior pattern can be changed at will by the use of appropriate stimuli which are detailed in our later pages. Barium therefore may be exonerated from the charge of influencing gastric behavior.

BARIUM AND PYLORIC PASSAGE

Just as we must vary our vehicle in order to study gastric features and function, so we must vary the vehicle for study of pyloric activity. If our purpose is a full outline of pyloric canal and duodenal cap we must use a vehicle like buttermilk which will maintain a suspension of barium. If we desire to study the rhythm of opening and closing of pylorus and its possible modifications we must change the vehicle accordingly. Buttermilk passage is a massive dense shadow usually with a full cap. Milk, which does not suspend the barium so well, is seen in passage as a puff, like smoke, which ill defines the canal and the cap. Water which does not suspend the barium at all and merely flushes out part of the precipitate, can only be seen as a trickle with dark particles of barium in its depths. The features of the pylorus appear to change with the type of vehicle swallowed. This of course is mere illusion but it illustrates the necessity of careful choice.

The somewhat erratic appearance of the duodenal cap requires a further word. As shown above its visibility depends upon adequate suspension of the barium but it is materially aided by pressure exerted either upon the cap itself or on the duodenum beyond. Clinically one would apply pressure if necessary but as our purpose is fulfilled by observing the behavior pattern unmodified by mechan-

ical means we are content to note the differences in outlines and constancy of appearance. The buttermilk suspension gives most of our information.

Just as barium, on entering the stomach, demonstrates the presence of waves, so its immediate passage betrays the patency of the pylorus in the "empty" or "resting" organ. This passage continues uninterruptedly for thirty or forty seconds before the pylorus closes. Thereafter the opening and closing of the pylorus depends upon the nature of the meal administered.

The mucus plug has already been mentioned. If this should fill the pyloric canal so that no barium can reach the pylorus of course immediate passage does not occur and indeed two minutes elapses in most subjects before the plug is dislodged, passed and the pylorus freed.

It is pertinent to ask at this point what causes emptying of the stomach. That our small fluid meals are not passed through the pylorus by peristalsis is evident at once. They do not pass by gravity or siphon action. The readiness with which any motility pattern, characteristic for the particular meal swallowed, changes after a definite period into a pattern which is constant for each stomach and practically uniform for all individuals bespeaks the substitution of the foreign fluid for a local one. In other words the stomach has been flushed by gastric juice. At this stage the reader may be sceptical concerning emptying of the stomach by flushing. Indeed we are not prepared to claim more than that flushing is the means whereby our small experimental meals are passed through the pylorus. If however the reader will mark the appearances described in later pages as characteristic of the several experimental meals administered he will be convinced that flushing by gastric juice is the main emptying force which we encounter.

DISTRESS AND ANXIETY COMPLEXES

The significance of emotional stimuli on the stomach has already been stressed. Indeed instability of response is characteristic of most stomachs when subjected to roentgenoscopic examination for the first time or after the lapse of a long period since the last examination. If the stomach has been previously accustomed to inspection it quickly recovers balance and its behavior pattern loses the erratic and unstable features.

In one of our articles (15) Miss Kuenzel and I have compared the reductions in area of barium shadow during the hour after administration of a barium meal to students at different periods of their training. The Freshman stomach immediately upon administration of a meal shows in February, on the average, a shadow of the same area as that cast the previous October. But whereas the October Freshman had not recovered stability in an hour the February Freshman has: the shadow area is proportionately more reduced. In October of the Sophomore year, although the stomach has lost a little of its stability, its recovery is very rapid and the reduction in area during one hour is quite striking.

Along with the general hypotony in shadow outline illustrated by the relatively large shadow area of Freshmen there is an inhibition of peristalsis which, on recovery, reappears first as shallow waves in the pyloric part and gradually deepening its amplitude, spreads over the entire stomach. Peristalsis invariably returns before the orthotony is restored.

Recognizing the disturbing effect of emotional factors we have developed a technique of training and observation by which the influence of emotional factors is minimized so far as possible. Some stomachs indeed, usually in subjects of even temperament, show only slight fluctuations in

tone and peristalsis at successive examinations. These we have termed tolerant or stable stomachs.

Few indivduals exhibit a tolerant stomach at the first examination. In nearly all the stomach shadow, controlled by measurements at later examinations, is long and broad. The peristalsis is feeble and often temporarily inhibited. Reduction in size of shadow and increased vigor of peristalsis are shown at successive examinations until, after practice, the responses to a constant stimulus are stabilized both in dimensions and motility. Such a stomach is recovering from what we term the distress complex. The emotional disturbance registered in progressively greater physical degree we have designated disquiet, apprehension, distress. In fear the disturbance reaches its climax. I have called attention in earlier pages to the striking effects of mental distress and fear. We have reason to believe that fatigue acts in similar manner though in less degree.

If trained stomachs show instability it is more apt to take the form of hyper-motility with a flocculent shadow characteristic of the mucus plug, perhaps even the small shadow dimensions of hypertony. These are characteristic features of the anxiety complex. Slighter aberrancy of this kind we call agitation but if it is greater, anxiety.

The arbitrary degrees of disturbance and the expressions used to define them are purely empirical but serve to illustrate the features of physical behavior for which one must be alert in roentgenoscopic examinations.

THE "CATCH" MECHANISM

The persistence of peristalsis in hypotonic stomachs and its return after inhibition before orthotony is restored are explained by the catch mechanism of smooth muscle. This is not the place to enter a purely physiological discussion. It may be recalled however that smooth muscle can maintain itself in a particular length-phase for con-

siderable periods without apparent continuous nervous excitation. Unlike striped muscle which functions best at a definite length-phase, smooth muscle can exhibit equally active motility in different length-phases generally defined for convenience as hypotony, orthotony, hypertony. Grützner has suggested that the fibers are "hooked" up so that they can be shortened by a slipping motion which locks the fibers in place. The "catch" which is Sir William Bayliss's term, can be put into action at any state of contraction, that is, with the fibers at any length, and when it is inhibited or released, the fibers may either contract or relax (See 14).

PERISTALSIS IN THE PYLORIC CANAL

Although we have made a very careful study of the subject we have found no evidence of a distinctive peristalsis of the pyloric canal. Nevertheless since peristalsis is often restricted to this section of the stomach the problem must receive some attention.

When, after inhibition from emotional or other fortuitous stimuli, peristalsis returns, it appears first in the pyloric canal. After the lapse of the latent period resulting from a stimulus like that of buttermilk or bicarbonate of soda peristalsis first appears in the pyloric canal. Again after peristalsis has been inhibited by a large meal, it reappears in the pyloric canal and only gradually spreads to include the more proximal part of the stomach.

Not infrequently the peristaltic wave increases in amplitude very markedly when it reaches the pyloric canal. Even the weak milk waves greatly deepen as a rule in the canal. It is necessary therefore to warn the reader against allowing his judgment of the forcefulness or amplitude of gastric motility to be influenced by the character of the waves in the canal.

The reverse side of the picture is found in our amyl

nitrite studies. After inhalation of this drug and before peristalsis is completely inhibited the waves can be followed along the greater curvature to cease at the junction of vestibule and canal. We have also observed this type of behavior in other forms of inhibition though with less regularity.

Since amyl nitrite acts locally through the blood stream I think it probable that inhibition first in pyloric canal is merely an incident of the vascular distribution. The peculiar and rather uniform vigor of pyloric canal peristalsis is probably equally an incident of the thickness of muscle.

THE EFFECT OF SIZE OF MEAL

It is well understood that although peristalsis is stimulated by distension it is easily inhibited by over-distention. What over-distension actually is may be a matter of argument. The important fact for us to remember is the ease with which gastric peristalsis is temporarily inhibited by contents. When one administers a certain measured quantity of fluid to a stomach under observation it is to be remembered that there will be a marked addition from secreted gastric juice and that this secretion continues over a period of time. A twenty-ounce opaque meal of water may give rise to painful distension accompanied by cold clammy perspiration, pallor, and other signs of distress, not because the twenty ounces overdistend the stomach but because of the tension caused by the rapid addition thereto of gastric secretion. Peristalsis will be immediately inhibited and may not be fully restored for thirty to forty minutes. Meantime the practically continuously patent pylorus is relieving the surcharged stomach.

It has been necessary for us to discard the conventional meal of twelve ounces of vehicle with four ounces of

barium because this, with the secreted juice, took too long to pass through the pylorus and inhibited peristalsis by sheer overdistension.

For the large meal we have substituted a five-ounce experimental meal consisting of four ounces of vehicle with one ounce of barium. Even with the secretion stimulated by the vehicle, this size of meal does not distort the cylindrical character of the stomach except in the pyloric vestibule.

Retention of the cylindrical cross section is very important for the practical purpose of estimating gastric volume from shadow area (see the resting stomach, p. 37). Nor does this small meal interfere with the peristaltic pattern as the large meal does.

For the purpose of studying the resting stomach we use, as an "outliner," half an ounce of water and five grams of barium. The water is very rapidly washed away by gastric juice leaving the precipitate of barium clinging to the mucosa.

FACILITATION

In our earlier experiments we obtained rather bizarre responses to the first meal given during a roentgenoscopic examination. To the second meal administered an hour later the responses were singularly uniform. It was the contrast between these two behavior patterns which induced us to adopt the technique of a preliminary meal. We gave this technique the title of facilitation. It is a very useful method of approach to the problem of gastric behavior but of course it means the abandonment of the results of the first experiment. This being expensive in time and in human material, we modified the technique by substituting the "outliner" for the first meal. This serves the purpose equally well, takes up much less time and gives us the advantage of being able to compare the responses

to our experimental meals with the natural gastric behavior (neutral pattern) for each particular stomach instead of merely contrasting one series of experimental responses with another.

THE VERTICAL DIMENSION OF THE MAGENBLASE

From time to time we shall have occasion to mention behavior in the fundus or Magenblase of the stomach. We have noted for example (6) a reduction in vertical height of stomach shadow with progressive training but this reduction may find no proportional counterpart in rise of greater curvature. It is in the Magenblase that the major change occurs. The entry of the oesophagus, if it can be defined, provides a very stable level from which Magenblase height can be computed, but the base of the gas bubble itself may not coincide with this level. In the water pattern and sometimes after other watery meals have been administered, gas from the Magenblase is sucked into the upper gastric tube. When a meal is swallowed elevation of the Magenblase can be clearly seen, the cupola of the diaphragm rising with it. In some of our subjects we have found the vertical increase of the Magenblase very marked, associated with extreme elevation of the diaphragmatic cupola. It may occur even before the meal is swallowed, being then an expression of nervous agitation. Doubtless, especially in the nervous cases, some of the gas is swallowed. Some appears to be formed locally in the stomach, for it comes as it also goes without evident passage along the gullet.

In all stomachs the reduction in Magenblase height goes on apace during the first twenty minutes and is quite marked at the end of an hour.

The slight respiratory distress sometimes occurring during the first twenty minutes after a meal appears to be associated with this phenomenon. The terminal cardiac

embarrassment in old bedridden patients may be intensified or even originated by the same cause. Curiously also we find increase in Magenblase height with elevation of the left cupola accompanying a cold drink or following the application of an ice pack to the abdominal wall. I imagine one of the reasons for preferring a hot drink to a cold just before retiring for the night is to be sought in this fact.

THE RESTING STOMACH

I suppose a really empty stomach would be as abnormal a condition as a dry mouth. It is not possible to determine the condition of the resting stomach by such methods as the introduction of a gastric tube or a balloon. Rubber in the mouth has a distinct effect on the amount and character of salivary flow and doubtless it has a similar effect in the stomach.

That gastric juice is readily and rapidly secreted in large amount can be seen in the distending shadow on roentgenoscopy. It is also demonstrated, as Mr. Sommerfield has shown (12), by applying Simpson's rule to obtain the stomach volume from the dimensions of the gastric shadow. With the small five-ounce meal which we prefer the stomach may be regarded as a curved tube circular in cross section, though this certainly does not hold for the usual large meals. If however we give a buttermilk meal of 150 cc. we may find the gastric volume within a few minutes risen to 800 cc. Even allowing a considerable error in our method, which I would not be prepared to admit, there must still be a considerable secretion of gastric juice.

We have, of course, no observations which unequivocally prove the presence of a gastric juice flow in the resting stomach and I merely suggest its probability. We do have evidence, already glanced at, of regular peristalsis and a patent pylorus in the resting stomach.

Taking the latter first, no matter what experimental meal is administered to a resting stomach we always find, in the absence of a mucous plug, immediate passage lasting thirty or more seconds before it ceases.

It is entirely independent of peristalsis which may be absolutely inhibited for the duration of the passage. If the open pylorus were not caught "unawares" this could not happen.

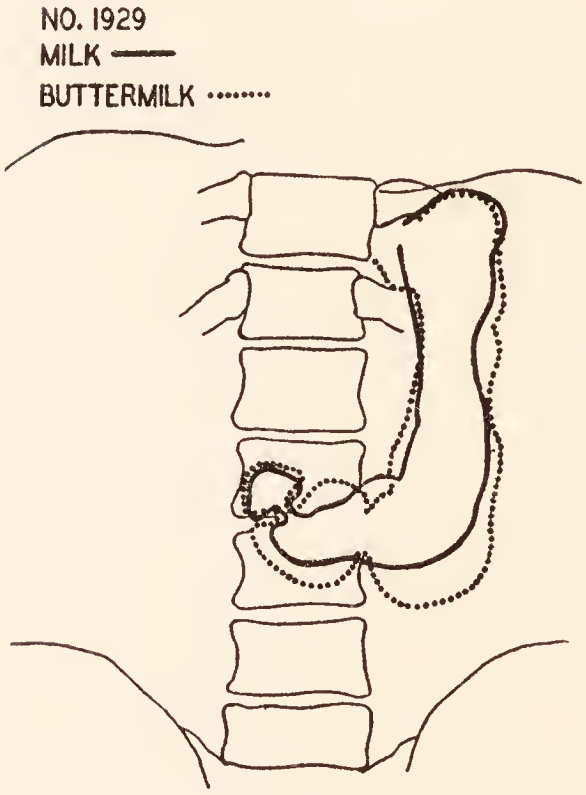


FIG. 6

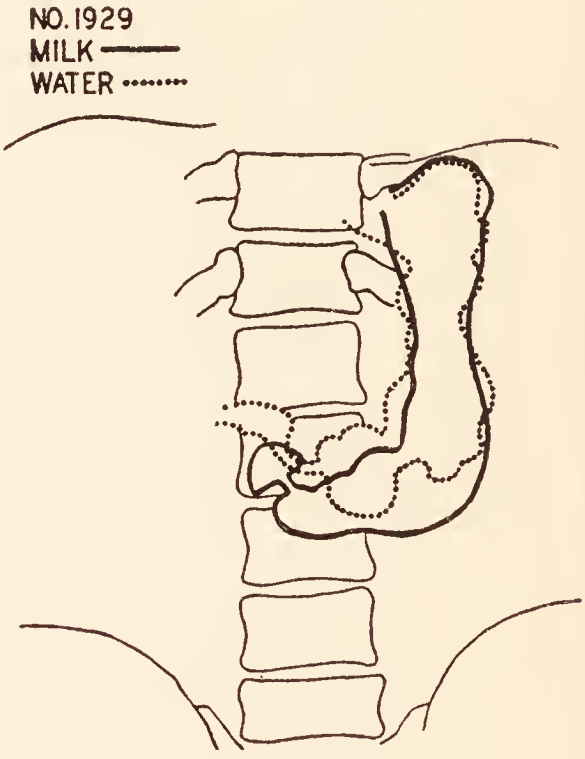


FIG. 7

See page 39 for legend

When one of our half-ounce water meals is given the peristaltic waves are outlined as the barium spreads over the greater curvature. I have already given reasons for assuring ourselves that these waves are not stimulated but are merely rendered visible by the barium. They are of quite moderate amplitude, not forceful in character, varying only slightly from individual to individual, range throughout the stomach on both curvatures though naturally most easily picked out on the greater, and of the same speed as the water waves in Graph I.

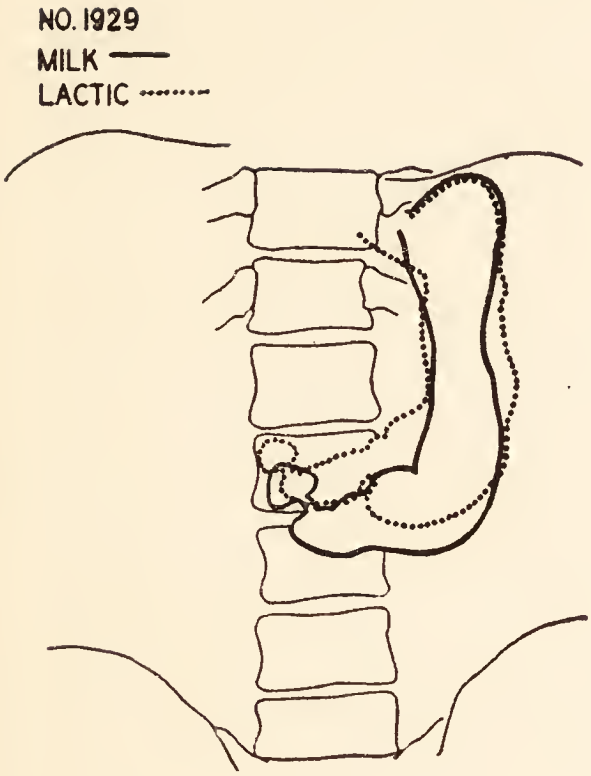


FIG. 8

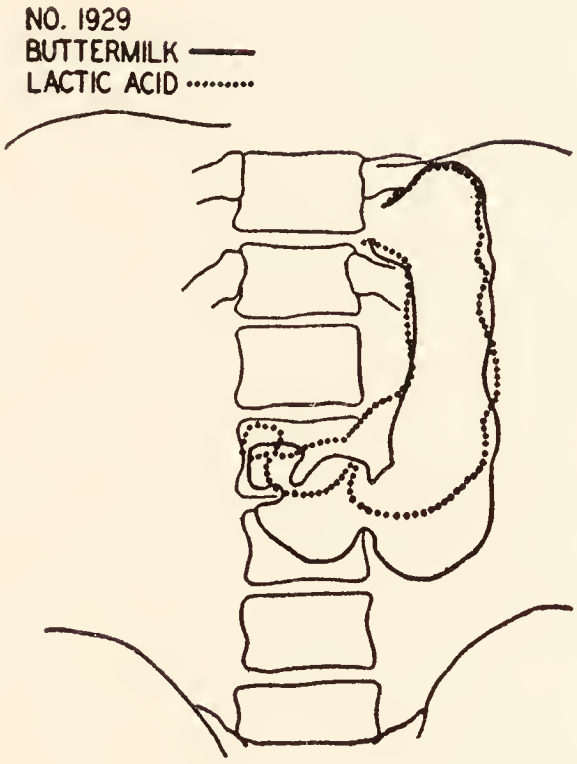


FIG. 9

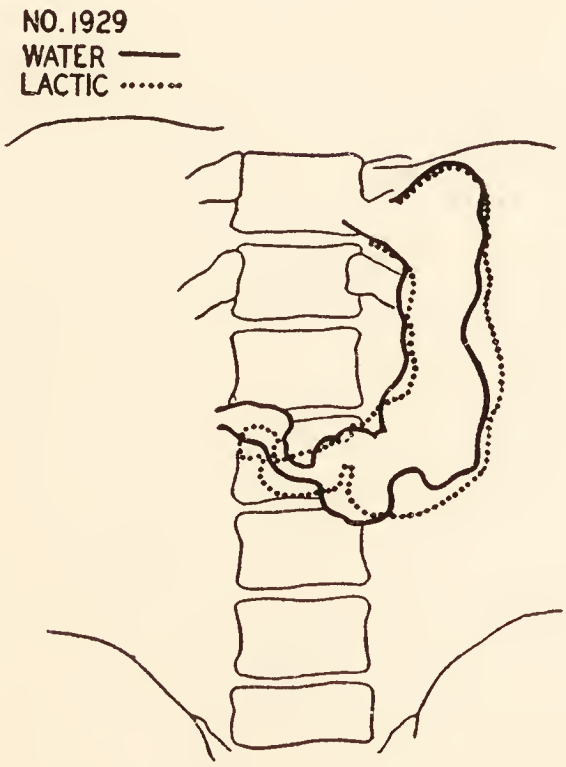


FIG. 10

FIGS. 6, 7, 8, 9 AND 10. Comparison of shadow area and activity. Five-ounce meals milk, water, lactic acid and buttermilk.

These neutral waves are usually known as hunger contractions. According to other observers (e.g., Carlson 3) they may be interrupted by periods of quiescence. We have not observed this but some detail in the technique of investigation may easily account for the difference in statement.

Gradually during the first two minutes after administration of the half-ounce water meal, the amplitude of the waves deepens, first obvious in the pyloric canal. Between two and three minutes after the meal they reach their greatest depth and begin to become shallower again. Within a few more minutes they have returned to their original amplitude, only the barium precipitate which clings to the mucosa registering their character. The sequence of observed facts can be explained only by the flushing by gastric juice of the water through the pylorus which remains almost constantly patent as can be observed by the telltale shadow particles of the barium carried in the stream. There is of course no reason to doubt the secretion of considerable gastric juice by the stimulus of water since this is well known already by amply-attested proofs.

THE INFLUENCE OF WATER ON GASTRIC BEHAVIOR

In discussing the barium outliner attention has been called to the observation that between one and a half and two minutes after the half-ounce of water with its contained five grams of barium has been administered depth and forcefulness of the peristalsis are increased. It has also been noted that five minutes or so after administration the neutral pattern is restored. Water is used in this outliner because it stimulates a considerable flow of gastric juice and maintains the pylorus almost constantly open. The restoration of neutral phase amplitude and vigor in so short a time indicates that whereas the barium precipitate

falls and clings to the mucosa the supernatant water is quickly flushed away and all trace of its action on gastric activity is soon at an end.

It was subsequent to and in consequence of our studies on the action of water that we devised the outliner. Suppose then that no outliner has been given but a regular small water meal takes its place. This means five ounces of water into which is stirred one ounce (30 grams) of barium. The stomach fills in waves, that is to say the neutral peristalsis is immediately outlined. The waves are visible on both curvatures but may be at once "frozen" as indentations in whatever position they happen to be. Since it is known that gastric peristalsis is quickly inhibited by tension this transformation of waves into identations means an inhibition pending adjustment of stomach volume to its contents. In a very few seconds the indentations begin to pulsate and are then transformed once more into waves passing along the stomach with moderate depth and speed but without any particular force. The restoration of neutral peristalsis lasts but a minute and a half from the time of administration. Thereafter wave depth and force increase but speed is unchanged. During this interval careful observation demonstrates almost continuous passage in spite of the temporary cessation of peristalsis. The lowering of greater curvature and lateral distension of gastric tube are both very slight and before long the gastric dimensions begin to be reduced once more. Passage, seen as a faint shadow with denser particles in its lower part, continues almost without interruption.

Three minutes after administration the depth and forcefulness have reached their limit of intensification and thereafter, until about ten minutes from the time of swallowing the meal, they are maintained in almost uniform degree, but now once more diminish and return to neutral amplitude and vigor.

The loss of characteristic water pattern means the final flushing out of water from the stomach, such barium as remains being merely a precipitate clinging to the gastric mucosa.

There are two other features of the gastric shadow characteristically present after administration of a water meal. The first of these is a very rugous outline of greater curvature which is associated with the relatively slight change in gastric dimensions induced by the meal. Since the pylorus remains almost constantly patent there is no chance for the stomach to fill up and distend. The rugosities of the mucosa are therefore never properly ironed out. To some extent, as we shall see later, this phenomenon is seen also after other watery meals but it is after water alone that the condition is really marked.

The second phenomenon is also a corollary of the rapid flushing of contents through the stomach. The gas bubble of the Magenblase is seen to extend momentarily and repeatedly down the gastric tube as if it were being sucked by siphon action.

Every feature of the water pattern then points to a rapid flushing of fluid through an almost continuously, perhaps indeed constantly, patent pylorus.

In the beginning, when the water meal is administered the barium may descend, not along the curvatures of a small tubular gastric tube but through fluid in a tube somewhat laterally distended. This means there has been previous secretion of gastric juice accompanied perhaps by swallowing of saliva, a condition especially apt to occur in a nervous subject who has had to wait a little while before the meal could be administered. There may be, in addition, a mucous plug. Quite rapidly however the picture is changed to one of characteristic water activity and thereafter the behavior pattern is that which has been described in the body of this chapter.

THE MILK PATTERN

When a five-ounce milk meal is administered to a trained subject who has previously had an "outliner" of barium the continuance of the neutral waves without interruption or modification and the immediate passage are the two features which would at once strike the observer. He gets the impression that milk has no effect upon gastric activity. It is to Mr. Eberhard that we owe the elucidation of the successive features of the gastric response to milk. Eberhard carried out an exhaustive analysis of serial roentgenographic records made by Miss Kuenzel and myself upon trained subjects.

The first specific feature of the milk pattern to receive notice is a negative one, namely the very moderate elongation and lateral distension indicated by the gastric shadow. There is so little alteration that one is apt to imagine the stomach has merely been enlarged by the introduction into it of 150 cc. of fluid which is rapidly passing away through the patent pylorus. However in thirty or forty seconds passage ceases and, although imperceptible on the screen, serial roentgenograms show that the shadow area and therefore the volume of the stomach is increasing until between two and three minutes after administration of the meal. Beyond this point the shadow area shows a slow but steady decline in size.

The pylorus which closed within the first minute opens again between two and three minutes after administration and thereafter displays a rhythmic alternate closing and opening of short and approximately equal periods.

On or slightly before the lapse of two minutes from the moment of administration the hitherto neutral peristaltic waves reduce their amplitude but do not modify their speed or frequency. This is the characteristic effect of milk on peristalsis. The amplitude is decreased until in many subjects waves are no longer visible as even shallow

progressing movements. They may be entirely replaced by purposeless wavelets which appear and disappear locally over the entire stomach, like flickerings of the shadow outline. This phenomenon we have called shimmer. It is not a substitute for nor yet a vestige of waves for we find it present over the regular peristalsis, even in the vigorous waves of buttermilk and soda. But it is more easily observed in the quiet stomach after a milk meal.

Between ten and fifteen minutes after administration the very shallow waves commence to deepen again and before the end of twenty minutes the neutral pattern is fully restored. It is then impossible to recognize from the gastric behavior what type of meal was given.

In no stomach is passage so clearly seen to be independent of peristalsis as in a milk stomach.

As the shallow peristaltic waves pass down the gastric tube the barium shadow can be observed to oscillate, jerking upward with the passage of each wave. This upward jerking is always present in peristaltic activity and is best marked when the waves are deep and rapid as in the water response.

In a milk suspension the barium sinks imperfectly to the lower part of the fluid mass.

Passage through the pylorus occurs in smoke-like puffs without adequately outlining the duodenal cap. The passage of the shadow can be followed round the duodenum but is lost near the duodeno-jejunal junction until some ten minutes after administration when it appears in the jejunum as flocculent masses. This period is actually the time necessary to curdle milk by rennet in vitro at 98°F.

The one and a half to two minutes which elapse between administration and the change in peristaltic pattern are the latent period of gastric response.

Milk and water have this feature in common, namely

non-interference with the neutral frequency of waves. Water increases the amplitude, milk diminishes it. With water the pylorus is practically continually patent: with milk it is rhythmically opened. Water stimulates much gastric secretion but does not cause much increase in shadow area because the fluid is readily passed through the pylorus. Milk, inducing less secretion, has a larger shadow because fluid passes only intermittently.

PART II

Gastric Behavior Patterns

gastric responses to heat and cold

It was perhaps fortunate that we chose milk as the vehicle for demonstration of the responses to heat and cold for the effect of milk at room temperature (70°F.) is a reduction in amplitude and peristalsis whereas both heat and cold increase it.

If a five-ounce opaque milk meal at 140°F. be drunk there is immediate lateral distension of the Magenblase without corresponding distension of gastric tube. The reason for this change in the Magenblase is not clear. It does not occur after application of heat to the abdominal wall: it is peculiar to a hot drink. The absence of even that moderate distension and elongation of shadow observed after milk at 70°F. is particularly noteworthy. The shadow area after a hot drink of milk is as small as after a drink of water at room temperature. This can scarcely mean reduction of gastric secretion but, instead, more frequent and more prolonged opening of the pylorus through which indeed the barium can be seen pouring.

The latent period of hot milk is very short. Almost immediately the depth, speed, frequency and vigor of the peristaltic waves are greatly increased but without any intervening pause such as that characteristic of cold or buttermilk. Gradually the typical heat modifications of peristalsis subside and the pattern reverts to the neutral type of behavior although this will not be fully restored until between fifteen and twenty minutes after the meal was swallowed. If the effect of heat passes off more quickly the quiet milk pattern appears before the neutral pattern.

It is particularly noteworthy that heat applied to the abdominal wall in the form of a hot pack for thirty to sixty minutes has more pronounced effect on gastric behavior than heat applied directly to the gastric mucosa. This is illustrated by following up the hot pack by a milk meal at 70°F. The modifications of neutral pattern are even better marked than after a hot drink but there is no lateral distension of the Magenblase. The shadow area is also smaller after externally applied heat.

Since the relative effects of heat applied externally and internally are parallel, as indeed are those induced by cold, we feel sure that the influence is exerted reflexly and not locally and directly.

When a drink of milk at 32°F. is given, or a regular opaque milk meal at 70°F. after 45 minutes' application of an ice pack to the abdominal wall, the peristaltic activity is increased as after application of heat but there is a latent period of about a minute and a half. The increased vigor of response lasts only about five minutes and rapidly falls away not to neutral type but to the scarcely perceptible activity characteristic of milk at room temperature.

The size of shadow area is not so easily distinguishable from that of regular milk if the stimulus is a cold drink. If the cold is applied externally there is the same effect as from external heat though less marked. After both external and internal application of cold there is upward distension of Magenblase a feature already mentioned on page 36.

The fact that there may be no intermediate regular milk inactivity between the vigor of the heat response and the supervention of the neutral type of behavior serves to emphasize the much more vigorous stimulus brought about by heat when compared with the effect of cold.

THE EFFECT OF A FOREIGN BODY ON BEHAVIOR PATTERN

To Mr. Held chiefly we are indebted for the studies of the effect of a rubber balloon in the stomach. It is an experience for which training is as necessary as for roentgenoscopic technique. Our purpose was to investigate the gastric activity by our regular methods at the same time as observations were being recorded on the tambour.

An ordinary condom attached to a catheter is swallowed after enough barium sulphate powder has been shaken into it to render it visible on the screen. We have not employed the double condom with barium paste between the two as this extra bulk is unnecessary. It may be advisable to cocainize the throat to facilitate swallowing because even an experienced swallower may have difficulty in getting the balloon and tube over the pharyngo-oesophageal junction and in refraining from vomiting the apparatus once it is in the stomach.

In early attempts we met with the accumulation of a large amount of gastric fluid, some being undoubtedly saliva but the majority, as we believe, local secretion for we watched it growing in quantity very rapidly under our eyes. With the accumulation of fluid the balloon is floated up into the Magenblase and of course registers diaphragmatic contractions and tremors and nothing more.

If excessive accumulation of fluid is avoided much gas may gather in the Magenblase, distending it to an enormous extent. Once again the balloon may remain in the greatly distended Magenblase and never penetrate the gastric tube. The tambour records heart and respiratory movements and other tremors but no peristaltic waves.

A third difficulty even if neither excessive secretion

nor gas is encountered is the instability and erratic flutter of the diaphragm associated with the early stage of vomiting. We have found this to occur even when the subject has not been conscious of nausea. There has been no evident tendency to vomit.

In view of such complications we have never felt very sure of our tambour records except in so far as they are checked by actual observation on the screen.

We have not had opportunity to watch the behavior of the stomach immediately the balloon enters and we are not in a position to discuss the immediate phenomena. Once however the balloon is fairly ensconsced in the gastric tube there is set up a very vigorous and fairly rapid peristalsis of deep amplitude, about four waves being seen at once and ranging throughout the entire length of the stomach. These appear to be neutral waves (hunger contractions) of great amplitude and force. If food is now swallowed there is reduction in amplitude of waves or even temporary inhibition. In other words the "digestive waves" emphasized by Carlson, visible only in pyloric canal, may supervene for a time.

THE STIMULATION BY LACTIC ACID

Our regular five-ounce water meal containing one ounce of barium acidified by lactic acid and buffered by sodium hydroxide to pH_4 gives us a meal of the approximate acidity of buttermilk. On administration of this lactic meal the Magenblase distends laterally but the gastric tube grudgingly responds so that the barium is apt to descend slowly into the pyloric vestibule which never gives one the impression of "weight" as it does after administration of buttermilk. It was indeed to study further and to analyse the influence of buttermilk that we introduced the lactic meal into our series.

The stomach fills in waves as after water administration

but instead of, at the most, a momentary "freezing" of the waves as indentations, there is a real temporary inhibition of gastric peristalsis. This transformation into indentations occurs as a rule only after a quick and trained eye has been able to recognize the existence of neutral phase waves. It is of course presumed that opportunity has been given for the subject to adjust himself to the conditions of examination and that the temporary inhibition of peristalsis on stepping to the roentgenoscopic screen, if it occur, has been overcome.

The total area of gastric shadow after administration of a lactic meal is somewhat greater than after a corresponding meal of milk but since the gastric tube fails to distend to any great degree, rugosities may be present in its outline as after water, though they are never so marked.

Following the inhibition of neutral peristalsis, within about a minute and a half, an altered type of peristalsis makes its appearance. The waves range as before over the entire stomach shadow and are visible on both curvatures, but they do not look like water waves for they are distinctly slower. Passage also is plainly intermittent but irregular in its rhythm. The peristalsis is less regular than after water. Occasionally the sucking of the Magenblase down the gastric tube occurs after lactic acid but this phenomenon is less frequent than after administration of water.

We do not know how lactic acid influences the flow of gastric juice but are led to infer that it is fairly copious and that the size of gastric shadow is an indication of the balance between flow of juice and patency of pylorus.

The impression given by lactic behavior is that it is really a modified water pattern and that the effect of the lactic acid is somewhat unequal in character, thus accounting for the irregularities observed.

Our observations do not permit us to claim that the

gastric juice, secreted under the stimulation of lactic acid, flushes the meal from the stomach with the same rapidity as water is flushed away. Our records do enable us to state definitely that, twenty minutes after swallowing the meal, gastric peristalsis has once more resumed its neutral character. In this respect lactic acid behaves more like milk than like water.

The shadow of passage closely resembles that of water, namely a light shadow with denser particles in its lower part. The cap is usually imperfectly delineated as after water.

In contrast with the water pattern, the lactic stomach shadow has a broad Magenblase, a rather broader gastric tube and pyloric vestibule and an elongated outline. The "cogwheel" and "ballooning" features so characteristic of water occur more rarely after lactic acid. Peristalsis is definitely changed from neutral type to a slower more erratic rhythm with moderate amplitude of waves. In the development of this change peristalsis ceases temporarily and is replaced by indentations visible along the greater curvature which first pulsate and then originate the new wave rhythm. Passage is more intermittent and erratic in interval and in amount. Gastric secretion is probably greater. After twenty minutes the waves are once more neutral in character.

THE RESPONSE TO BUTTERMILK

The most striking reaction of the stomach to a five-ounce buttermilk meal is the rapid increase in dimensions of the shadow and the modification of peristaltic rhythm.

Immediately the barium buttermilk meal enters the stomach the shadow of the gastric tube begins to distend laterally and the greater curvature sinks in the region of the pyloric vestibule, giving the observer an impression of fluid weight. As usual the neutral waves continue for a

few seconds and are then inhibited completely. The pylorus is patent as seems generally to be its immediate condition on swallowing a fluid meal. Since barium is really suspended in buttermilk passage is obvious as a massive dark shadow, usually accompanied by a full duodenal cap. If there is already fluid in the stomach, say the remnant of a water or milk meal, it is shot through the pylorus in advance of the buttermilk.

The pylorus remains open for the best part of a minute and passage is continuous while the dimensions of the gastric shadow are increasing and the neutral peristalsis is inhibited. The pylorus then closes and no more barium passes into the duodenum for sixty seconds or more.

About one and a half or two minutes after administration a new peristaltic rhythm is set up. The waves are similar in depth and forcefulness: the speed is lessened and the number of waves passing at one moment over the stomach is reduced from three or four to two or even one. In all these features the response to buttermilk resembles the lactic acid pattern. But the rhythm of buttermilk waves is regular, that of lactic peristalsis is erratic. Since the barium remains suspended in the buttermilk, lesser curvature waves are seen equally as clearly as those on the greater curvature. The opening and closing of the pylorus is demonstrated as a rhythmically intermittent passage and the barium shadow can be observed easily on its way through the duodenum into the small intestine.

The large shadow dimensions remain almost unimpaired for a considerable time and it is only towards the end of the twenty minutes that they are much reduced. At that time also the peristalsis speeds up and is diminished in amplitude and force, so that the neutral phase pattern returns and all trace of specific buttermilk activity is lost.

The obviously great gastric activity with the massive dark shadows of passage give one the impression of a

stomach rapidly emptying itself. But at the end of an hour about the same amount of barium is still clinging to the mucosa as after a milk meal. It is certain therefore that the massive shadows of passage bespeak only a better suspension of the barium and not a bulkier or more rapid evacuation.

When one considers the rhythmic opening and closing of the pylorus the explanation of great increase in gastric shadow dimensions becomes apparent. It is not that there is a proportionately large gastric secretion but the fluid in the stomach is banked up by closure of the pyloric orifice. A rugous "cogwheel" outline and a "ballooning" of the gastric tube by downward temporary extension of the Magenblase, such as are characteristic of water, never appear after a buttermilk meal. Oh the other hand one quite frequently sees shimmer superposed on the deep, massive and forceful buttermilk waves. Buttermilk waves are not quite so slow in their progress as those of lactic acid but they are more uniform and their rhythm is more regular.

The buttermilk used in these experiments is that known as "plain lactic." It is not the "creamed lactic" variety. It is in fact ordinary milk acidified with lactic acid by a commercial process. Its precise acidity varies somewhat but is about pH_4. Buttermilk bears the same relation to milk that our lactic acid meal does to a water meal. One would expect therefore that there would be a similar relation in the gastric responses. Just as the lactic acid deepens and renders more forcible the peristalsis and diminishes speed and frequency of waves compared with the water response, so buttermilk produces a like modification when compared with the milk pattern. But the buttermilk rhythm is far more regular than that of lactic acid.

GASTRIC REGULATORS: SODA AND PEPPERMINT

Having now seen that gastric motility can be modified by the administration of various simple reagents provided their action is not masked by the introduction of a local stimulus like a rubber bag or interfered with by stimuli of central nervous origin we can proceed to a more practical study, namely the action of the simple stomachic mixture. We refer to the ordinary therapeutic dose of barium

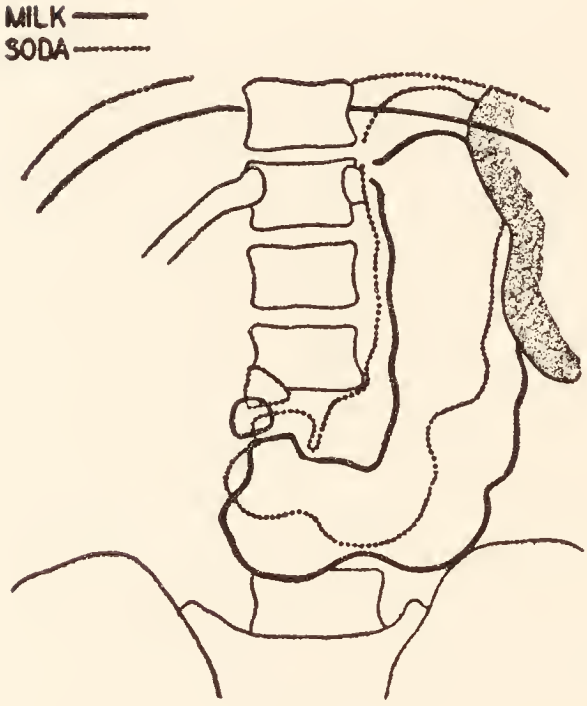


FIG. 11

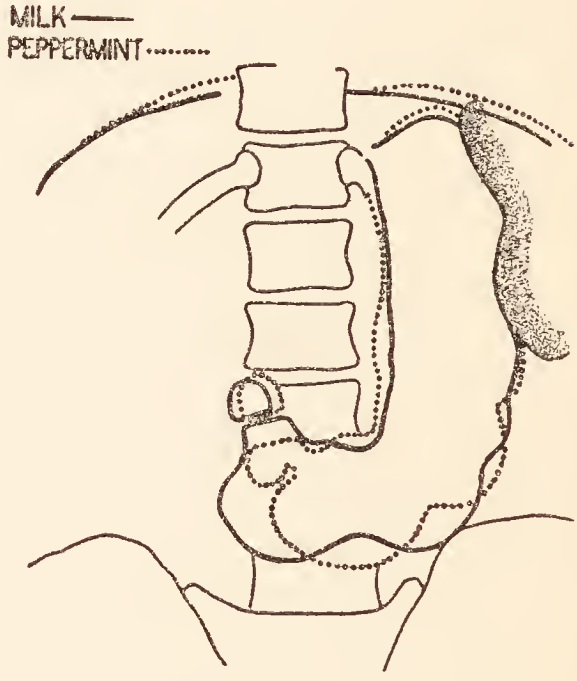


FIG. 12

FIGS. 11 AND 12. Comparison of shadow area and activity. Five-ounce meals milk, soda and peppermint.

or bismuth and bicarbonate of soda with peppermint as a carminative. It is especially important to obtain a clear idea of the carminative action for recorded observations on this subject have hitherto been most conflicting, undoubtedly owing to the conditions of experimentation.

Now, in our investigations, we find that soda and peppermint induce an identical gastric response; hence the actions of these reagents may be considered together. As for the heavy metal, we have already set forth our reasons for be-

lieving that barium in therapeutic doses has no influence on gastric motility. It merely clings to the mucous lining. There is no reason to assume that bismuth would have any more definite action.

The reactions to soda and peppermint were of course studied separately and compared with responses to control meals of water or milk, trained stomachs only being utilized in this as in every other phase of our final investigation. Both meals were regular water meals. But to the one we added thirty grams (two drams) of sodium bicarbonate, to the other ten minims of spiritus menthae piperidae. The soda and the carminative reinforce each other's influence.

After administration of either the Magenblase and gastric tube distend somewhat though not nearly so much as after buttermilk, and the greater curvature descends a very moderate amount. Since barium is no more easily suspended in a soda or peppermint meal than in a regular water meal the shadow of passage is grey and faint with some small darker particles in the lower part.

As after buttermilk the initial passage occurs and neutral peristalsis is rapidly halted and then eliminated. After the usual latent period waves appear again but very different indeed from those they replace. Two at once is nearly always the maximum, visible on both curvatures, extraordinarily slow, deep, steady, regularly rhythmic and so forceful that they appear to nip the shadow almost into two as if it were being cut by a guillotine. Not infrequently indeed the stomach shadow momentarily resembles the ace of clubs with the pyloric vestibule as the middle lobe. This energetic action continues to increase from its inception until about three minutes after administration. Twenty minutes after taking the meal the neutral pattern is restored and every vestige of action induced by the experimental reagent is lost.

Very rarely we have seen a special distension of the Magenblase with gas after soda administration, carbon dioxide being no doubt evolved locally. But this is no part of the characteristic pattern.

So regular and so active is the gastric response that we have called both soda and carminative gastric regulators. Even this strenuous peristalsis has little or no effect upon the propulsion of a fluid meal but should there be solid or semisolid gastric contents it is inconceivable that the peristalsis would not greatly facilitate its passage.

The action of these two gastric regulators is very similar to that of buttermilk but far more powerful and constant in its effect. No matter how active, how lethargic or how erratic the stomach movements may be before the introduction of soda or peppermint, the result is always the same afterwards. Individual differences scarcely exist.

We come to a rather difficult problem when we attempt to explain how it is that the action of an acid fluid, lactic or buttermilk, produces a similar result to that obtained by the administration of an alkali like soda. It may well be however that the stomach is stimulated by the anion in each type of experiment. Further investigation of the reaction is needed but of the result there is no doubt at all.

THE LARGE BARIUM MEAL

Our small five-ounce meal is of particular advantage in studying gastric motility because the response stimulated reaches its full characteristic pattern three minutes after administration and has died down completely in twenty minutes at the most. The stomach is ready for another meal at the end of an hour. For some special purposes however a large meal is necessary. We use, in the large meal, four ounces of barium sulphate to twelve, or even on occasion sixteen, ounces of vehicle. If so large

a meal as this be made up with water the subject may suffer from acute dilatation, abdominal distress, even severe pain, a cold sweat and pallor. This is probably due to the over-stretching of the stomach by copious gastric secretion which adds itself to the contents swallowed. After a few minutes the distension and distress moderate themselves and, a little later, disappear. Emptying through the pylorus is probably the cause of the relief.

If so large a meal be given neutral peristalsis ceases immediately and it may be many minutes before the new waves begin. We expect to have to wait from fifteen to thirty minutes before the peristalsis is fully developed. Of course the stomach is completely outlined, both lesser curvature as well as greater, and if one desire to study wave speed and range the large meal is quite useful.

GENERAL SUMMARY OF GASTRIC PATTERNS

Having now followed the several modifications of gastric behavior encountered in our experiments it is worth a moment's pause to recapitulate briefly the characteristics of each.

Between meals there pass, over the entire stomach with fair regularity and speed, waves of moderate amplitude and no particular forcefulness. These "hunger contractions" or, as we term them, neutral waves have been recorded by others to show intermissions of half an hour at a time. Except for temporary inhibition from central nervous stimuli we have found them always present in our examinations. They continue for some seconds after the administration of our "outliner" or our small regular meal but are immediately inhibited by a large meal.

The latent period which elapses before the appearance of the characteristic behavior pattern stimulated by the fluid administered is about ninety seconds.

A five-ounce meal of water or of milk causes little interference with the neutral pattern. There may be no inhibitory pause or but a momentary one. The neutral rhythm is maintained, three or four waves being present at one time. Water however increases depth and forcefulness of the waves whereas milk reduces both. Three minutes after administration of a milk meal there may be no appreciable waves but only a "shimmer." After about ten minutes the characteristic neutral depth and strength of wave returns whether water or milk has been administered.

After water the pylorus is almost constantly patent so that in spite of the profuse gastric secretion there is but little increase in gastric shadow area: "cogwheel" and "ballooning" effects are present. After milk, on the contrary, the pylorus is intermittently open and with less secretion the gastric shadow dimensions are greater than after water.

Buttermilk and lactic acid show a very definite latent period of a minute and a half during which neutral peristalsis ceases but the pylorus continues patent with consequent uninterrupted passage shadow. The characteristic deep forceful slow waves then commence. The first usually starts at junction of pyloric vestibule and canal, the next at mid-vestibule, the third at junction of gastric tube with pyloric vestibule and the fourth in the gastric tube itself. The fifth can usually be seen to originate just beneath the Magenblase. Usually not more than two waves are visible at any one time whereas, after water or milk, three or four may coexist. The progressively higher origin of the initial waves is quite characteristic of gastric peristalsis. It is also characteristic that forcefulness increases the nearer the wave gets to the pylorus. Often there is a sudden accession of vigor in the wave as it passes along the pyloric canal. Indeed waves may be seen in this location

only, especially after a large meal. They have been called by others "digestive" waves, a term which we believe is founded upon an erroneous interpretation and very prone to mislead the reader.

The differences between lactic acid and buttermilk of comparable acidity are, first, the more erratic response to the former, and secondly, the greater dimensions of gastric shadow after administration of the latter which has some peculiar power in keeping the pylorus closed for longer intervals than any other vehicle studied by us.

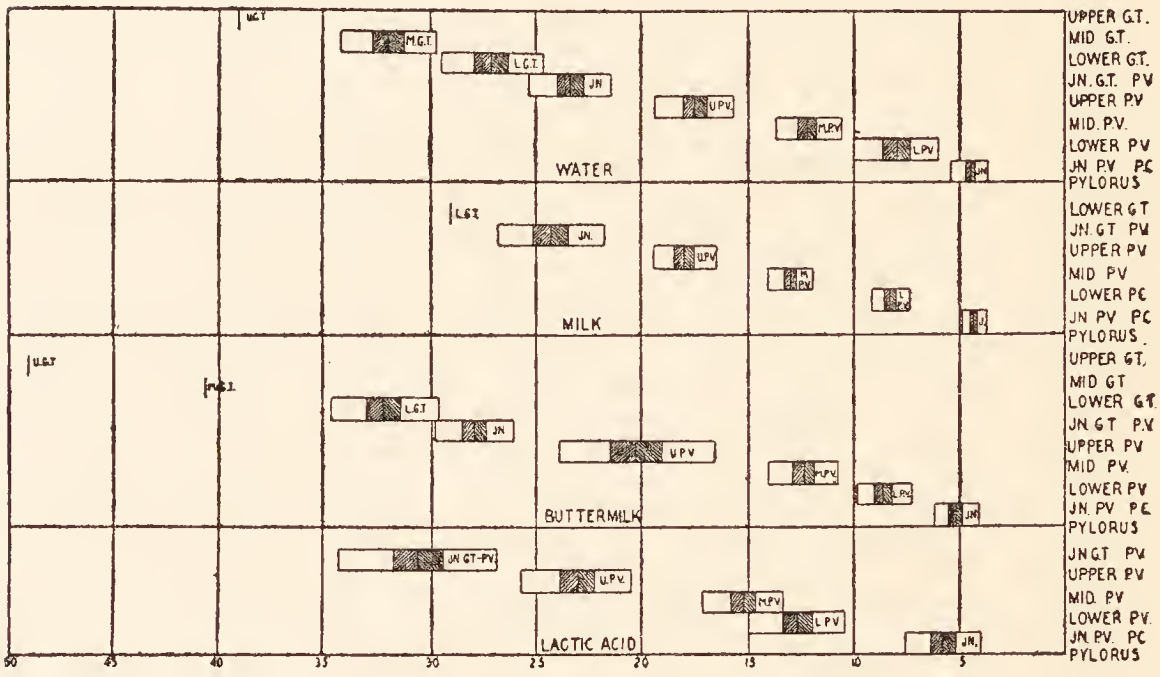
Soda and peppermint act as gastric regulators. They have a powerful influence and convert any degree of activity or non-activity into a regular deep forceful, very slow peristalsis which even cuts up the gastric shadow into a trefoil-like outline. Initial inhibition and latent period are comparable to those of buttermilk.

The neutral pattern returns between ten and fifteen minutes after administration of a five-ounce water or milk meal but between fifteen and twenty minutes after any one of the other experimental meals just mentioned.

Heat and cold are more effective applied to the abdominal wall than as hot or cold drinks. A hot drink results in a broad Magenblase apparently by distension of cardiac end of stomach from constriction of gastric tube. Cold, either internally or externally, distends the Magenblase upward and may distress the heart. Both heat and cold increase depth and vigor but do not change the neutral rhythm very much. At first, it is true, they speed up the peristalsis but this rapidly returns to neutral rhythm. In five minutes after administration of the meal in the "cold experiment" gastric peristalsis is weaker and the stimulating effect of cold is at an end. Heat usually continues to influence the stomach until some fifteen minutes after administration of the meal.

TIMING THE GASTRIC WAVES

Space does not permit an adequate discussion of timing the gastric waves. Miss Kuenzel and Mr. Sommerfield have made a special study of this phase of our subject (10). From their results I have drawn up Graph I. Here are the average times with their standard deviations and the indicators which show the approximate limits of stragglers



GRAPH I. COMPARISON OF SPEED OF PERISTALTIC WAVES

Five-ounce meals of water, milk, buttermilk and lactic acid. The central line indicates the average time, the hatched area the standard deviation and the limits of the oblong figure the dispersion of straggler waves.

among the waves so that we may note the relative activity after meals of water, milk, buttermilk and lactic acid. There is little time distinction between milk and water patterns, but there is a definite slowing of the wave after buttermilk and a still more marked slowing after lactic acid. The slowing moreover becomes progressively more marked in those portions of the stomach nearer the cardiac end.

The effect of heat and cold is less easily shown. The

speeding up of the waves is quite marked with both forms of stimulation but the influence of cold is of much shorter duration than that of heat.

THE INHIBITORY EFFECT OF AMYL NITRITE

For the study of gastric spasm the use of atropine has disadvantages which are too obvious to need specification. The employment of amyl nitrite by Doctor Beams at Lakeside Hospital has been very successful in diagnostic work. We have therefore made a special study of its action.

A regular five-ounce water meal is administered and the characteristic behavior pattern of water permitted time to develop. The subject, still standing behind the screen, then inhales a capsule of amyl nitrite. Within ten to fifteen seconds the gastric peristalsis, if not entirely inhibited, is greatly repressed. Curiously enough it is the peristaltic wave in the pyloric canal which suffers earliest and longest. Naturally the degree of inhibition varies with the resoluteness of the subject in inhaling the drug. By the time the cutaneous flush is felt in the face the gastric effect is at its height. Three minutes after inhalation peristalsis returns to its previous activity with a suddenness comparable to the speed with which it was lost. The effect of amyl nitrite is the same upon smooth muscle in the vascular system and in the stomach.

THE ROUTINE GASTRIC EXAMINATION

Building upon the results of our experiments described in the foregoing chapters we have greatly modified our routine clinical gastric examination.

The patient is not starved. He eats a light breakfast of his own choice and presents himself about two hours later for study.

The administration of an "outliner" serves to introduce

him to the routine and enables us to record the disposition of his stomach, its landmarks and its activity in neutral phase. Within five minutes of administration the water pattern is exchanged for neutral behavior.

Ten minutes later we give a five-ounce meal of milk and observe the effect. If the stomach shows a typical milk pattern the peristalsis is reduced in vigor or perhaps replaced by shimmer. If the time relationships are normal no further investigation of motility may be necessary though we usually complete the study by a meal of soda or buttermilk. A normal stomach will respond to stimulation in the manner and with the time relationships above described.

This examination is often adequate to demonstrate carcinoma, linitis plastica and even the filling defects of ulcer, though for the latter a larger meal may be necessary accompanied by pressure which should also be resorted to for examination of the duodenal cap. Often however the stomach shows irregularities or abnormalities in motility and general behavior so that a page devoted to these will not be out of place. The clinging of barium to the gastric mucosa must not be mistaken however for undue retention or obstruction.

THE HYPERACTIVE STOMACH

Hyperactivity of the stomach is always present in the anxiety complex and in patients consciously or subconsciously nervous but not afraid. Since there is no distinction in pattern between it and the hyperactivity which precedes pyloric or duodenal ulcer precautions should be taken to determine its transient or quasi-permanent form.

Administration of milk results in an increased vigor of peristalsis. The neutral rhythm remains but the waves are deep and forceful, quite unlike normal milk waves. The pattern indeed resembles that of buttermilk but the

gastric dimensions are not those of buttermilk; the speed is not that of buttermilk. The waves also are broad for their depth, not narrow as after buttermilk. In other words this is a milk pattern in which peristaltic vigor is increased instead of being reduced. If a contrast meal of buttermilk be given later, it is only by noting the gastric shadow dimensions and the slowness and deeply notched character of the waves that the buttermilk pattern can be differentiated from the abnormal milk response. A patient exhibiting a stomach of this type is undergoing strain. A second examination after a few days will demonstrate whether this was transient or not. The presence of a mucous plug suggests a transient "anxiety." If the hyperactivity is still present some general advice is distinctly indicated.

THE LETHARGIC STOMACH

Frequently a lethargic stomach, of relatively great dimensions and low peristaltic activity, is the result of physical fatigue or of the distress complex. It is found in mental shock, acute disappointment, fear or depressing mental strain. Even buttermilk or soda may be inadequate to stimulate a reasonable response. In our experience it is usually temporary in nature and treatment should be directed to relief of the cause. It is also present however in obstruction when compensation has broken down. If such a condition is suspected further examination for the cause of obstruction should be undertaken. Appetite and digestion are distinctly interfered with. A mucous plug may be present as in a hyperactive stomach.

THE DUODENAL CAP AND PASSAGE

There is not much light thrown upon the duodenal behavior by our experiments so far. An adequate suspen-

sion of barium such as that characteristic of buttermilk is necessary for proper examination of the duodenum.

Frequently, without pressure, only the base of the cap is seen. In quite normal subjects there may be deformation due to a bubble of gas in the upper part of the cap and there is great variation in size of cap.

Massive peristaltic waves can be seen passing over the duodenum after a buttermilk meal and not infrequently there is a regurgitation of barium upwards in the vertical or second part of the duodenum. These little streams of upward movement we have termed "prancing particles." It has been impossible to decide whether regurgitation through the pylorus ever occurs. If it does there is no great amount regurgitated in normal subjects.

At the junction of vertical and horizontal parts of the duodenum there is frequently temporary retention exaggerated by the weight of pyloric vestibule pressing upon the third part. In fatigued or otherwise hypotonic stomachs this "cesspool" condition may last several hours. It clears up with restoration of normal gastric activity.

The Small Intestine

Barium can be seen passing along the jejunum immediately after a buttermilk meal but its speed is so great that peristalsis cannot be observed. Serial radiography will however bring this out. The ladder coils of small intestine, never penetrating the flanks, are obvious especially in somewhat obese abdomens.

The other meals do not permit the tracing of barium through the jejunum except by roentgenography. After milk however the jejunum is outlined about ten minutes after the meal is swallowed. This is the approximate time which rennet takes to curdle milk at body temperature. The delayed appearance is therefore probably due to entanglement of barium in the coagulated milk.

The ileum becomes visible an hour after administration of any vehicle. These coils are always in the lower abdomen and in the true pelvis.

The speed with which the barium shadow disappears from small intestine into the colon is a measure of the activity of the organ. Usually all barium has passed out of the ileum in about eight or nine hours. In hyperactivity associated with a like condition of the stomach or colon the barium shadow is lost from the ileum in four hours.

PART III

The Large Bowel

GENERAL FEATURES OF THE COLON

Colonic behavior is quite a different problem from that of the stomach. Its motility is far more complex and investigation much more difficult. The variety of its movements in pattern and in time-relationship is striking. The erratic occurrence makes observation expensive in time, supplies and human material.

There is no definite length for the large bowel nor any uniform arrangement of its parts. The anatomical relationships observed in the dissecting room are more characteristic of the conditions in death than of the disposition during life. The caecum, usually confined to the right iliac fossa, may under certain circumstances find temporary or permanent partial disposal on the true pelvic brim or even in the true pelvis itself. But of course, through failure of embryonic rotation, it may lie adjacent to the gall-bladder beneath the liver or, with the rest of the large bowel, in the left half of the abdomen. The ascending colon varies much in length and may be doubled over in front of the upper caecum. The hepatic flexure lies anywhere from the neighborhood of the right iliac crest to the level of the tip of the tenth right rib or even higher. Although large sacculations mark the outline of the colon from caecum to hepatic flexure these are usually rather indefinite on roentgenoscopy which, in our experience, always records a capacious form.

Unlike the foregoing parts the transverse colon shows well-marked haustra which are more clearly delineated by pressure on the abdomen. In disposition the transverse

colon varies greatly. Sometimes it dips into the true pelvis. Rarely, even in the horizontal posture, does it travel across the abdomen without some declination of its middle part. Always more capacious near the hepatic flexure, the reduction in its caliber towards splenic flexure is gradual. That part which lies immediately beyond the hepatic flexure is disposed in a sigmoid curvature known to the French as the hepatic loop. The outline of this loop is often obscured roentgenoscopically since it lies immediately in front of the ascending colon.

The splenic flexure is more constant in position than the hepatic and studies by Mr. Reider show that it is less fluctuating in site on serial roentgenography. In many subjects it lies higher in the abdomen than the hepatic flexure but it also may be found within the left iliac fossa.

The part of the colon between splenic flexure and rectum is relatively far more variable in length than other portions. If the flexure lies above the iliac crest there is a descending colon arbitrarily delimited by flexure and crest. From crest as far as brim of true pelvis the large bowel is known as the iliac colon. The segment beyond the brim, as far as the pelvi-rectal junction which is rather constant in position at the level of the third sacral vertebra, is the pelvic colon. After death none of these areas displays haustra like the transverse colon but during life they are disposed in sacculations like haustra of generous dimensions. These sacculations are visible in the active distended colon: they may be almost absent when the gut is elongated in distension or shortened and contracted as the descending and iliac portions seem usually to be both in life and death. The pelvic colon, always found in the abdomen of the young child, sinks into the true pelvis of the adult except when distended with gas or other contents. Under such circumstances it may greatly elongate and in this the iliac colon may participate, giving rise to

loops, apparently obscure in explanation, disposed in the left flank. The capacious right abdominal part of the colon and the restricted caliber of the left abdominal portion are to be associated with the clinical observation that haemorrhage is characteristic of cancer in the former and obstruction in the latter.

The caecal mesentery is usually obliterated in the adult of the dissecting room but in our young healthy students the caecum can be freely moved by digital pressure. The ascending colon, hepatic flexure and the right limb of the hepatic loop are also mobile to some extent in the living though after death they may exhibit no mesentery. The transverse colon proper always has a mesentery. The splenic flexure, descending and iliac colons are usually without a mesentery and though the splenic flexure is by no means fixed its range of mobility, like that of the descending and iliac colons, is quite restricted. The extent of the mesentery of the pelvic colon is very variable. How much it may alter with changing conditions of the bowel is by no means clear. After death it may be nonexistent though a permanent restriction during life of pelvic colon to a length of some six inches is hardly believable.

Anomalous disposal of colon and distribution of mesenteries receive no particular attention in this account.

TECHNIQUE OF INVESTIGATION

There are three simple methods of studying the appearance and effects of colonic activity. The first is the administration of a meal of some material easily recognizable in the stool, such as canned or fresh corn. A record of its emergence can readily be made by a coöperative subject. The times at which its presence is noted and the number of stools in which it occurs give a rough estimate of colonic behavior.

The other two methods depend upon an opaque meal studied in the bowel itself. The meal may be given by mouth or as an enema.

In this account we shall record only our experiences in administration by mouth. For colonic examination a large meal of four ounces of barium with twelve of vehicle is most satisfactory. A lesser quantity may be used as an "outliner" and indeed we often give one of our five-ounce meals on the day previous to the gastric examination so that the relations of stomach and colon may be observed. A five-ounce meal is not large enough to give full definition to colonic outline and does somewhat interfere with the observation of small intestine shadows. It has two significant advantages namely accustoming the subject to the taste of barium and giving the observer information on the state of the colon and the possible existence of emotional stimuli at the first gastric examination. If at our roentgenoscopic session the subject takes two five-ounce meals an hour apart, as he often does, no further administration of barium is necessary.

For those who like it we use buttermilk as vehicle for the special colonic meal since it suspends the barium more readily than other agents, thus facilitating any preliminary observations.

THE EXHIBITION OF EMOTIONAL RESPONSES IN THE COLON

In the earlier part of our investigations on the colon we never saw, in Freshmen or Sophomores, movement other than respiratory rise and fall of transverse colon. After three years, however, in some Sophomores only, we observed very definite slow peristalsis in transverse colon alone. Unless the haustra are quite clearly defined the details of this peristalsis cannot be followed. When the abdominal wall is thin and the haustra plainly visible it is

apparent that the movement is a genuine peristalsis originating in the hepatic loop and continuing for a varying distance at about half the speed of neutral waves in the stomach. Frequently the movement makes its appearance first about two minutes after the subject has taken his stand behind the roentgenoscopic screen. When it is present we have watched it throughout the ten minutes of observation which we permit ourselves. The phenomenon has never yet made its appearance during our examination of Freshmen.

Admitting the intermittent character of colonic movements we nevertheless surmise that the occurrence of peristalsis in trained subjects and its non-appearance in the untrained are indications that emotional conditions may handicap and even inhibit colonic peristalsis.

A far more definite picture of emotional interference with colonic pattern is presented in the spastic bowel. This is associated more with the anxiety complex than with mental distress. It is most definitely demonstrated in the transverse colon and exists in varying degree for days together at a time. It may be localized to the left part of the transverse colon or may involve the entire length, barring the hepatic loop. Both circular and longitudinal coats are implicated so that the transverse colon is shorter than usual and crosses the abdomen more horizontally. The haustra appear as tiny wizened ghosts of themselves faintly delineated by barium or they are entirely obscured in outline so that gaps appear in the shadow. That some relaxation occurs from time to time is evident in the barium shadow beyond the spastic area. Passage of contents along the colon is greatly delayed and serial roentgenography may show increasing engorgement of the bowel proximal to the spastic portion with very slow forceful peristalsis of terminal ileum. Haustral pattern may be very clear in hepatic loop and even in ascending

colon for, after all, the peculiar character of haustral pattern is but a phase of colonic activity. As haustra are an expression of tone, a generous saccular outline might be interpreted as orthotony, small narrow haustra as hypertony of varying degree. The reservation which we would make in using these terms is merely that they indicate nothing more than length-phases of the smooth muscle. Neither the capacious caecum nor the contracted left (descending, iliac) colon is, in any sense, hypotonic.

The most marked instances of spastic colon are met with in subjects under high pressure of mental work or in financial or domestic anxiety. A rough measure of the degree and persistence of the spasm may be obtained by administering a large dose, say three ounces, of magnesium sulphate and noting the time of its elimination. With a normal colon this should occur in forty-five to sixty minutes. A spastic bowel may delay it for hours. The method must be used with care for there is some danger of absorption as a consequence of long-delayed elimination. Purgatives are not appropriate medicine for the spastic bowel. A small dose of atropine or belladonna will often relieve the condition but the true treatment is removal of the psychic cause.

NORMAL ACTIVITY OF THE LARGE BOWEL

I. The entry of barium

Passage of barium from small to large bowel may be expected about two and a half hours after the meal is swallowed but in a subject whose gastro-intestinal patterns are unknown it will be well to examine the ileo-caecal region one hour after the meal and every half hour thereafter till the passage commences.

The lower ileum distends with contained barium mixture and it may be difficult or impossible to identify the coils as they lie in the true pelvis: the terminal coil erects itself

and rather suddenly there appears a streaming pencil of barium shadow which passes upwards and to the right along a narrow channel about six inches in length. The presence of this channel, the ileal sphincteric tract, has so far not been betrayed by any trace of shadow. The fluid mixed with barium then pours through the ileal orifice and descends to the bottom of the caecum where it forms a pool. How far this action is intermittent or how long the sphincteric tract permits passage to continue we cannot definitely say. We believe it varies but have conclusive evidence in serial roentgenograms that, intermittently or continuously, probably the former, it has been kept up, on occasion, for half an hour at a time.

Unless the first shadow of passage is seen the original caecal pool is missed. Soon the caecum is filled with a rather faintly flocculent shadow which is intensified as more and more barium passes over from the ileum. As the ileal coils empty themselves, slow peristaltic action taking place the while, their outline becomes better defined and the caecal peristaltic movement is plainly seen.

The sphincteric tract itself shows very definite regular peristalsis while contents are passing through it.

II. Activity of the proximal colon

By the term proximal colon we refer to that part between ileo-caecal orifice and splenic flexure. As the contents of the ileum pour through the sphincteric tract into the caecum the latter distends and elongates after the manner of the stomach so that its blind lower end reaches, or even descends beyond, the pelvic brim. Very quickly the barium flocculence spreads itself as a faint shadow as far as the hepatic loop. The outlines of ascending colon and hepatic flexure are now recognizable. Meantime the shadow in the caecum becomes denser as more contents are poured into it and slow massive movements occur

involving its entire outline. How they can drive the contents onward is altogether obscure but the dense barium shadow does progress upward, filling, erecting and even elongating the ascending colon, the haustra of which now become very obvious. The diameters of the caecum are once more reduced though it will repeat the routine just described with every accession of further ileal contents. The shadow reaches caecum after two hours and a half and attains the hepatic flexure after four hours.

Equally without warning the flocculence spreads suddenly, like a puff of smoke, along the transverse colon, a barium shadow being distinct in the splenic flexure after six hours.

Peristalsis of intermittent type now can be seen, affecting one segment after another. It is considerably slower than the gastric neutral waves. The haustra are but incidental to these waves. How long are the periods of activity we cannot say: we have records of peristalsis continuing for three hours without intermission. It is probably irregular in occurrence and duration. A serial roentgenographic study may demonstrate disappointing lack of activity. However, even so, there is an alternate elongation and shortening of the transverse colon, apparently involving the taeniae. It produces a concertina-like movement of the horizontal part of the transverse colon. In the event of there being a distal vertically placed portion the similar elongation and shortening of this part results in oscillation of the horizontal part up and down in the abdomen. This appears to, but does not really, bear any relation to respiratory movements.

Examined in detail the peristaltic wave resolves itself into contraction of successive haustra, singly or in groups of two or three at a time. The change in haustral outline is not necessarily symmetrical on each side of the longitudinal taenia. The haustrum may be entirely obliter-

ated, changed to a bifid figure or subdivided into two parts. In the vertical part of the transverse colon there is induced an almost worm-like twisting upon the long axis so that, when the descending colon also casts a shadow, it is quite difficult to disentangle the shadows of the two segments. We have looked in vain for reversed peristalsis in the normal colon but we have repeatedly seen it in the spastic bowel. Alternate katastalsis (peristalsis directed aborally) and anastalsis (directed orally) are indeed rather characteristic patterns in a spastic bowel.

We have never yet been fortunate enough to see peristaltic rush but its mechanism is clearly similar to that of the ordinary spreading of contents along a segment of gut. The barium shadow does not gradually progress but takes over an entire segment of the colon at once, it may be the area up to the hepatic flexure, the entire transverse colon to the splenic flexure, the combined descending and iliac colons, or the pelvic colon, and lastly the rectum. Having thus taken over a segment more contents are poured in so that the shadow becomes denser, the proximal parts of the gut growing more flocculent and fainter in outline.

III. Activity of the distal colon

The distal colon, extending from splenic flexure to rectum, presents no difference in type of motility from the proximal colon, so far as our observations afford evidence. The barium shadow, always flocculent and large when descending, iliac or pelvic colon is entered, becomes denser, reduced in size and often subdivided into separate masses. The dehydration of contents is therefore more apparent in this part of the colon. Between nine and twelve hours after the meal a barium shadow can usually be observed stealing along the distal colon as far as the pelvic brim.

No information can be obtained upon colonic movement

by examining the subject when he experiences the call to stool for the transference of contents from distal colon to upper rectum has already taken place. It does seem however that actual defecation is the signal for a new accumulation of contents in the higher distal colon but the rapidity with which this occurs seems quite variable.

With the dehydration of contents and consequent reduction of their volume the generous saccular outlines disappear, the colon seems to shorten, segmentation becomes grotesque in appearance and finally loses all semblance of haustral form.

ANASTALSIS AND HAUSTRAL MOVEMENTS

Anastalsis and the details of haustral activity have already been discussed under the heading of the proximal colon in which they are most readily studied. The former is best seen in that segment of a spastic bowel immediately beyond which the actual contraction is found. The latter are easily stimulated by a high barium enema which does not fall within our present survey.

THE HYPERACTIVE COLON

I have mentioned the arrival of contents in the caecum two and a half hours after the meal. We do however find a shadow in the caecum within ninety minutes in patients who show general hyperactivity of the alimentary tract. The ileum may be entirely emptied and the large bowel occupied by barium as far as the junction of iliac and pelvic colons within six hours. In these patients the stomach and small intestine are likewise very active indeed. At first sight one might mistake gastric behavior after a five-ounce milk meal for typical buttermilk peristalsis. If the patient be given a corresponding buttermilk meal a little later the distinction between the two is easily made. In spite of the amplitude of the milk waves, they are broad

compared with their depth and less forceful than those of buttermilk. Moreover the dimensions of gastric shadow are, as usual, less after the milk than after the buttermilk. It would be invidious to suggest that the hyperactive alimentary tract is the earliest sign of a possible pyloric ulcer. We have encountered many unusually vigorous tracts which, though under observation for several years, have not yet developed symptoms of gastric or duodenal ulcer. Nevertheless hyperactivity has been evident in those of our students who have later presented symptoms of ulcer.

The Central Theme of Study

This record of gastro-intestinal observation, while recognizing the value of the more purely experimental investigations and descriptive accounts of other workers, presents a point of view hitherto but little emphasized. It is the viewpoint of the behavior pattern. We are not concerned with the precise positions or levels of significant features which act as landmarks in the alimentary tract. Our attention is occupied with the response of the digestive system to stimuli of local, reflex or central origin. We have therefore devised our studies to cover the reaction of the stomach to very simple stimuli, water, milk, acid, alkali and carminative. The responses to heat and to cold directly or indirectly applied, to foreign bodies and to emotional interference have been investigated under carefully controlled conditions which permit fairly complete analysis.

We have attempted to submit the colon to a similar scrutiny.

Our investigations have been planned and carried out on groups of healthy young coöperative subjects of both sexes. Each experiment has included a sufficient number of subjects and has been repeated on the same subjects under the same conditions until we have data enough to

give confidence in the uniformity of response. Over four hundred students have assisted us in the work, the permanent records of which, in notes at roentgenoscopic sessions, actual roentgenograms with serial studies and the motion picture reductions of these, now amount to a formidable mass of evidence and a mine of data for further analysis.

If however the reader has grasped the central theme of all our work, namely the fundamental significance, in health and in disease, of the behavior pattern in a study of the alimentary tract, we shall rest well content, knowing him to be in a fair way to amplify and extend these studies which by their very nature can be prosecuted in the physician's office.

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